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UTILITIES DELIVERY IN ARCTIC REGIONS. 1977.

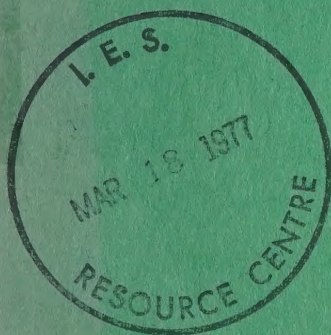
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Utilities Delivery in Arctic Regions



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Economic and Technical Review
Report EPS 3-WP-77-1

Water Pollution Control Directorate
January 1977

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PROCEEDINGS

SYMPOSIUM

ON

UTILITIES DELIVERY IN ARCTIC REGIONS

held

March 16, 17, 18, 1976
Edmonton, Alberta

Sponsored by

Northern Technology Centre
Water Pollution Control Directorate
Environmental Protection Service
Fisheries and Environment Canada

and

Department of Civil Engineering
University of Alberta

Compiled and Technical Editing by
Daniel W. Smith, Ph.D.
Northern Technology Centre

Report No. EPS 3-WP-77-1
January, 1977

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FOREWORD

The delivery of utility services, such as supplying water to and removing wastewater from individual buildings in permafrost regions, is technically difficult and extremely expensive. During the last twenty years, a great variety of systems have been used in attempts to provide these services. Techniques such as above and below ground utilidors, various amounts and types of insulation around pipe, alternative means of heating and supporting the piping systems, and the use of centralized facilities, have all been examined. The availability of new materials and equipment, as well as better heat loss prediction models, has resulted in more sophisticated and durable systems. The learning and development process has, however, been costly. A great deal of the work which has been done has not been reported in a fashion which would allow wide dissemination of the results. One objective of this meeting was to provide the needed forum for discussion of recent work in the area of utilities delivery in permafrost regions.

The program was divided into five basic areas: early developments; examination of thermal conditions; design guidelines; equipment and materials; and, case studies. A total of 30 technical presentations were made at the symposium. Of those presentations, 28 manuscripts were submitted for inclusion in this volume.

Special acknowledgement must be given to Mr. Ian Scott, Commission Counsel, Mackenzie Valley Pipeline Inquiry, for the presentation of an excellent overview of the Inquiry's work. A special thank you is also due the session moderators: Messrs. P.H. Bouthillier, E. Davis, H.S. Hrudey, A.R. Pick and J.J. Gravel for their assistance. The contributions of Mr. P.M. Higgins as the Banquet Master of Ceremonies, and Dr. J.D. Salloum for his opening remarks are gratefully acknowledged. The staffs of the Department of Civil Engineering, University of Alberta, and the Northern Technology Centre contributed greatly to the success of the symposium and their efforts are sincerely appreciated.

D.W. Smith

AVANT-PROPOS

Les services d'utilité publique, tels que l'alimentation en eau et l'évacuation des eaux usées des établissements des régions de pergélisol, présentent des difficultés d'ordre technique en plus d'être extrêmement coûteux. Au cours des 20 dernières années, des systèmes très divers ont été employés pour tenter de fournir ces services. On a étudié plusieurs techniques telles que les collecteurs souterrains et en surface, diverses sortes d'isolants et en quantité variable pour recouvrir les canalisations, des solutions de rechange pour le chauffage et le support des conduites et l'emploi d'installations centrales. L'apparition de matériaux et d'équipement nouveaux et l'élaboration de meilleurs modèles pour prévoir la déperdition de chaleur a permis de concevoir des systèmes plus complexes et plus durables. Toutefois, l'expérimentation et la recherche ont coûté très cher. Le mode de présentation du rapport pour une grande partie des travaux ne se prête pas à une diffusion massive des résultats. La réunion avait pour but de fournir aux intéressés l'occasion de discuter des études les plus récentes sur les services d'utilité publique dans les régions de pergélisol.

Le programme comptait cinq divisions: les premières tentatives, l'examen des conditions thermiques, les lignes directrices de la conception, l'équipement et les matériaux et les études de cas. Au cours du colloque, 30 communications techniques ont été présentées et les manuscrits de 28 d'entre elles composent le présent ouvrage.

Nous remercions tout particulièrement M. Ian Scott, conseiller de la Commission d'enquête sur le pipe-line de la vallée du Mackenzie, qui nous a présenté un excellent aperçu du travail de la Commission. Nous tenons également à remercier les modérateurs de la séance, MM. P.H. Bouthillier, E. Davis, H.S. Hruday, A.R. Pick et J.J. Gravel. Le rôle de M. P.M. Higgins comme maître de cérémonie du banquet et le discours d'ouverture du Dr J.D. Salloum sont aussi dignes de mention. Le personnel du département de génie civil de l'Université d'Alberta et du Centre de technologie du Nord ont contribué grandement au succès du colloque et nous leur en exprimons notre reconnaissance.

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SESSION I

EARLY DEVELOPMENTS

TRENDS IN CANADIAN WATER AND SEWER SYSTEMS SERVING NORTHERN COMMUNITIES

by

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INTRODUCTION

My assignment is to review the previously installed and the currently developing water and sewer systems with which I am familiar in the Canadian North. The paper is intended to set the scene for more detailed technical discussions to follow later in the seminar. Since it would be impossible within the short time available to review all the northern community systems, the development of water and wastewater distribution and collection systems is reviewed in key communities to establish trends with time.

STATEMENT OF PROBLEM

In the temperate climatic regions of Canada, water and wastewater utilities (piped systems) are normally buried below the frost penetration level so that freeze-up and soil instability problems are minimized. In the continuous and discontinuous permafrost zones, other expensive strategies are employed to service communities with water supply and sewer lines because of the problems created by thermal regime disturbance.

The differences between northern and more southerly systems can be summarized as follows:

- 1) Northern systems must operate continuously at below freezing ambient temperatures for eight months of the year and therefore heat must be applied to the system by some means to prevent freeze-up.
- 2) Installation of utilities in areas subject to permafrost makes below ground systems difficult and expensive to design, construct and operate because differential thawing causes differential soil settlement and pipe failure.

- 3) Usually systems are located in very small communities of less than 1000 persons having little or no tax revenue or skilled labour.
- 4) The systems must be designed for ease in operation and maintenance because of the remoteness of most communities.
- 5) Utility systems in the north are usually many times more expensive to construct and operate because of the need for insulation and heat addition as well as high transportation and labor costs.

Historically the northern communities have established their first community water supply and waste disposal facilities as haulage systems particularly in the permafrost areas. Later as the communities became more affluent or as government assistance became available, above ground or shallow burial summer water distribution and wastewater collection systems were constructed. The eventual goal of most of the communities has been to have year-round, piped water and wastewater utilities similar to their southern counterparts. Recently, the Northwest Territories Water and Sanitation Policy confirmed this trend and officially concurred with the gradual development of piped systems. The policy established population levels at which conversion from haulage systems to piped systems became economical.

TRUCKED SYSTEMS

These simple systems consist of individual water and waste storage tanks in each home having sufficient capacity to supply or retain the needs of a family for two to five days. Vehicles equipped with insulated 1,000 to 1,500 gallon tanks constantly supply the potable water and haul away the liquid wastes for disposal. The disadvantages of such a system are obvious.

- 1) The size of tank limits the water consumptive activities in the home and sanitation tends to deteriorate.
- 2) The operational costs of such a system are high because of the labour intensive nature of the process. A usual price

for water supply and sewage disposal ranges between 1.5¢ to 2.5¢/gallon.

- 3) Considerable inconvenience exists for each consumer.

From public health, economic and sociological points of view, piped water and sewer systems become more desirable particularly when the health care costs are included in the economics.

PIPED UTILITY SYSTEMS

Because of the Canadian trend to increased installation of piped utilities, the bulk of this discussion is oriented to outlining the materials, and designs utilized to overcome the prime problem in northern systems - prevention of freeze-ups and soil instability.

Originally the pipes were buried and heated water was continuously pumped through the lines at high rates to prevent freeze-ups. In permafrost areas differential settling usually occurred with this type of system and the above ground utilidor systems were conceived. The above ground systems were high in capital costs because,

- 1) greater insulation is required because of heat losses induced by greater temperature differential and wind chill;
- 2) support structures are required;
- 3) rugged exterior construction is needed to prevent damage from traffic movement and vandalism; and,
- 4) high costs of appurtenance structures and road crossings.

As new low heat transfer insulations such as urethane and polystyrene, and powerful hydraulic backhoes became available to deal with permafrost construction, the trend has reverted to buried insulated utilities which do not interfere with traffic movement and are more aesthetically desirable in the community.

In general, the strategies used to combat system freeze-up and permafrost instability were as follows:

Water Supply

1. Add heat by ensuring continuous flow.

High pumpage rates and bleeding of water to sewers at dead ends are required. Per capita pumpage rates as high as 600 gal/capita/day have been experienced.

2. Reduce heat transfer by added insulation.

Insulation of water and sewer lines with appropriate thicknesses of fibre glass, loose fill and plastic foams for both above and below ground installations has been practiced.

3. Add heat to the pumping system.

Tracing of the utility lines with recirculated steam or hot water was the original strategy and, more recently, electric resistance heating cables strapped to the pipes have been used.

4. Add heat to the recirculated flow.

In most cases a portion of the water is recirculated through a heat exchanger at the distribution pumphouse to raise the temperature of the return water to 40°F. In some cases higher temperature well water has been blended with the main source of supply to achieve the same result.

5. Combination of the above.

In the specific cases described, a combination of all the above is usually used.

The most common area for freeze-ups to occur is in the service connections. The methods used to prevent service freeze-ups are as follows:

Dual Service Lines

- (a) Use a specially shaped orifice at the inlet and return to the main (pit orifice) which ensures a constant flow through the service line.

- (b) Continuously circulate water through the service by means of a fractional horsepower recirculation pump.
- (c) Provide service from a high pressure distribution line and return water from the house through an orifice in the house to a low pressure return main.

Single Service Line

- (a) Continuously bleed water to the sewer.
- (b) Heat-trace the service lines either continuously or under thermostatic control.

In permafrost regions where the integrity of the thermal regime must be maintained to ensure stability of the pipelines, above ground utilidor systems or below ground systems require extra insulation to minimize heat loss.

SEWAGE COLLECTION

In most cases gravity sewers have been employed in the northern communities and the following strategies have been used to prevent freezing:

- 1) Add heat through a continuous supply of sewage.
- 2) Insulate to reduce heat loss.
- 3) Trace with steam, hot water, electrical resistance cables or install against warm water supply line.

SPECIFIC CASE STUDIES

In northern Canada - north of 60^o latitude - all the communities have a minimum of haulage systems. The communities which have been selected to describe the trends in water supply and sewage collection are located on Figure 1. All the above strategies have been used to prevent freezing and differential settlement.

Dawson City, Yukon Territory

In 1904 a buried water and sewer system was installed which is still operating and has recently been established as an AWWA/WPCF historical monument. Water is drawn from the Yukon River and heated to



FIGURE 1. COMMUNITIES SELECTED FOR CASE STUDIES

45°F, then pumped through a looped wood stave distribution system buried to a maximum depth of 4 ft in a well drained coarse gravel permafrost soil. Individual services are continuously bled to the sewers resulting in a per capita pumpage of 800 to 2,000 gpcpd. The heat applied through the water system is depended on to keep the wood stave sewer lines thawed.

Yellowknife, N.W.T.

Although continuous permafrost is not prevalent in Yellowknife, deep frost penetration, permafrost ice lenses, rock and muskeg must be overcome. Originally, a two-main recirculation water system was installed at a 6 to 10 ft depth. Water was pumped from Great Slave Lake, heated to 40°F and pumped to the system. Dual copper service lines were provided with flow discharged from the high pressure to the low pressure return main through an orifice plate in each house. Moss was used as insulation in areas of permafrost and ice lenses. The entire system was initially graded for drainage in the event of power failure. More recent additions to the system have been installed as recirculating loops. Considerable water bleeding is practiced to keep the services thawed and thermostatically controlled heat tracing is employed on new services. The sewers are asphalt coated corrugated metal pipe buried close to the water lines.

Norman Wells, N.W.T.

Norman Wells has been the scene of considerable utility system development over the years. It is located on a poorly drained permafrost soil. During World War II an army camp was constructed to build the Canol Road. Underground wooden utilities insulated with rock wool, traced with steam pipes, condensate return pipes and containing both water and sewer pipes were installed. Because of inadequate insulation, thawing of permafrost, frost heaving, line breakage and freeze-ups occurred.

Based on this experience, when the Department of Transport (DOT) established their housing complex, the underground utilidors were replaced by the wooden above ground utilidors shown in Figure 2. The utilidor was set on 3" diameter steel drill stem piles. The utilidor contained:

- 6" diameter cast iron sewer;
- 4" diameter steel water line;

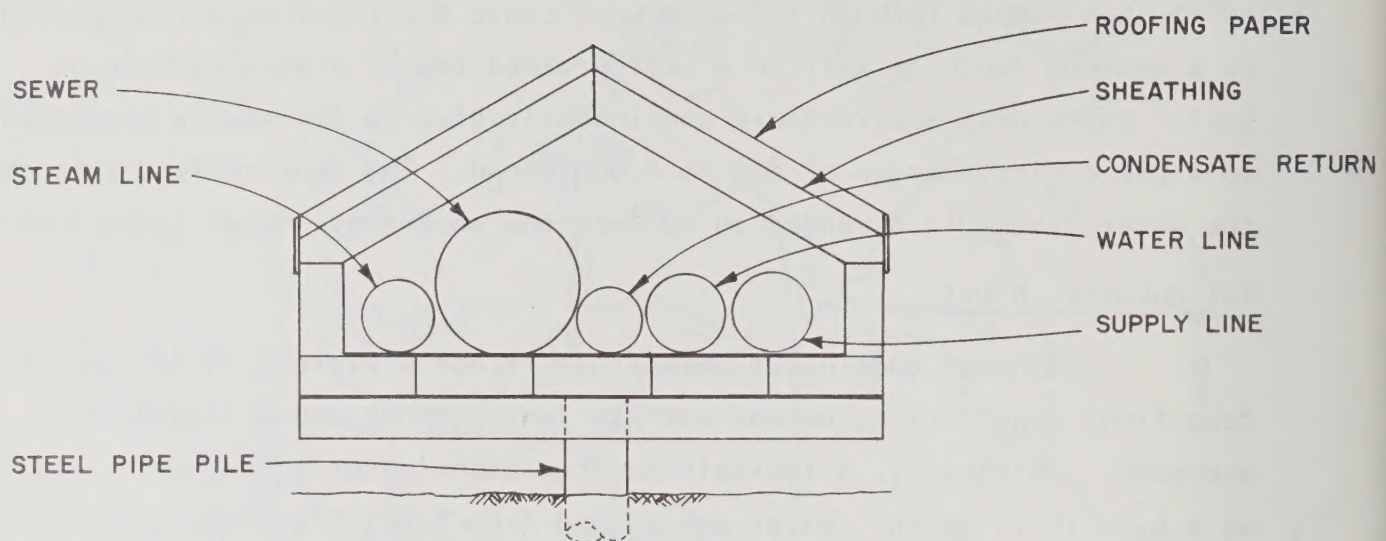


FIGURE 2. UTILIDORS AT NORMAN WELLS, DEPT. OF TRANSPORT, 1954-1965

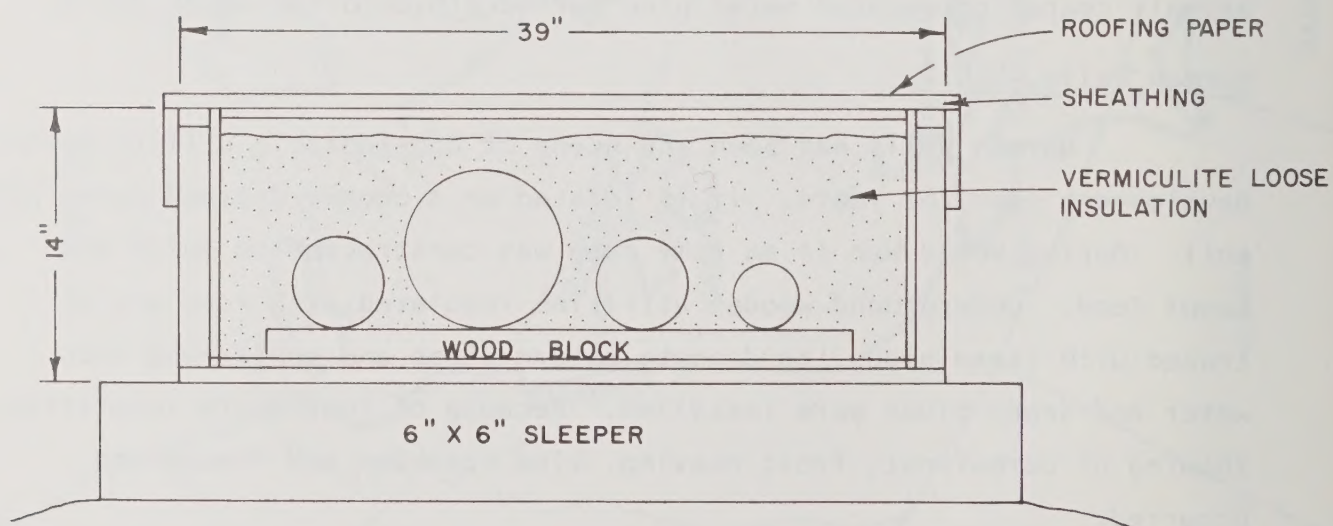


FIGURE 3. UTILIDORS AT NORMAN WELLS, IMPERIAL OIL LTD., 1954

- 4" diameter steam line;
- 3" diameter condensate return line; and,
- 4" diameter fire supply line.

Rock wool insulation was used. Insufficient attention was paid to steel pile design and frost heaving caused misalignment of the pipelines.

In 1954, Imperial Oil Ltd. developed the improved wooden box utilidor, shown in Figure 3, which was set on wooden sleepers on a gravel pad insulating the lines from the permafrost. Although this strategy solved the vertical alignment problems, the wooden utilidors deteriorated because they were not sufficiently rugged. The most recent utilidor development installed in 1965 by DOT consisted of the semi-circular corrugated metal utilidor concept shown in Figure 4. The split culvert design with vermiculite loose fill insulation set on a gravel pad has been a very rugged utilidor concept which is very easy to construct and maintain: it has a low profile which is aesthetically pleasing and has a relatively low cost of approximately \$150/ft. Basics of this design have been used at many communities in the Northwest Territories.

Inuvik, N.W.T.

Experience gained at Norman Wells was applied to the design of the most extensive and successful utilidor system in the Canadian North. In 1956, when a portion of the Aklavik population was relocated in the model northern community of Inuvik, a structural steel framed utilidor with a cross-section of approximately 3 ft x 3 ft was constructed. As shown in Figure 5, it consisted of:

- 8" to 11" diameter high temperature water lines for central heating (supply and return lines) set at the top of the utilidor on roller bearings;
- 6" diameter asbestos cement water supply line;
- 8" diameter asbestos cement sewer;
- 22 gauge corrugated aluminum siding;
- 3" thick fibre glass insulation; and,
- 2" - 10" diameter timber pile supports at 10' spacing.

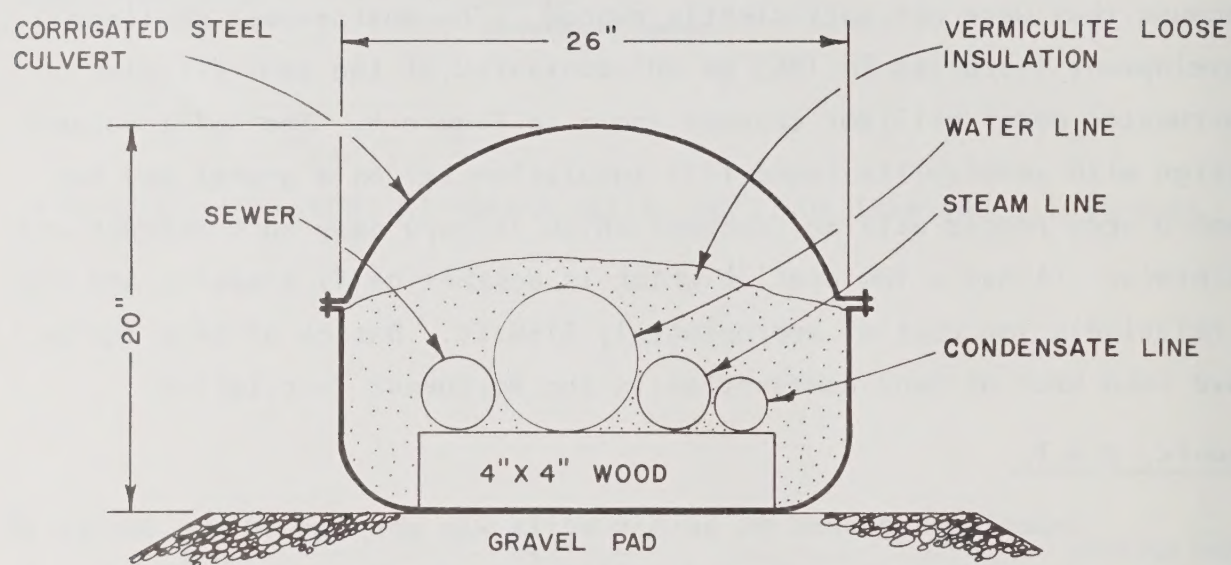


FIGURE 4. UTILIDORS AT NORMAN WELLS, IMPERIAL OIL LTD. AND DEPT. OF TRANSPORT, 1965

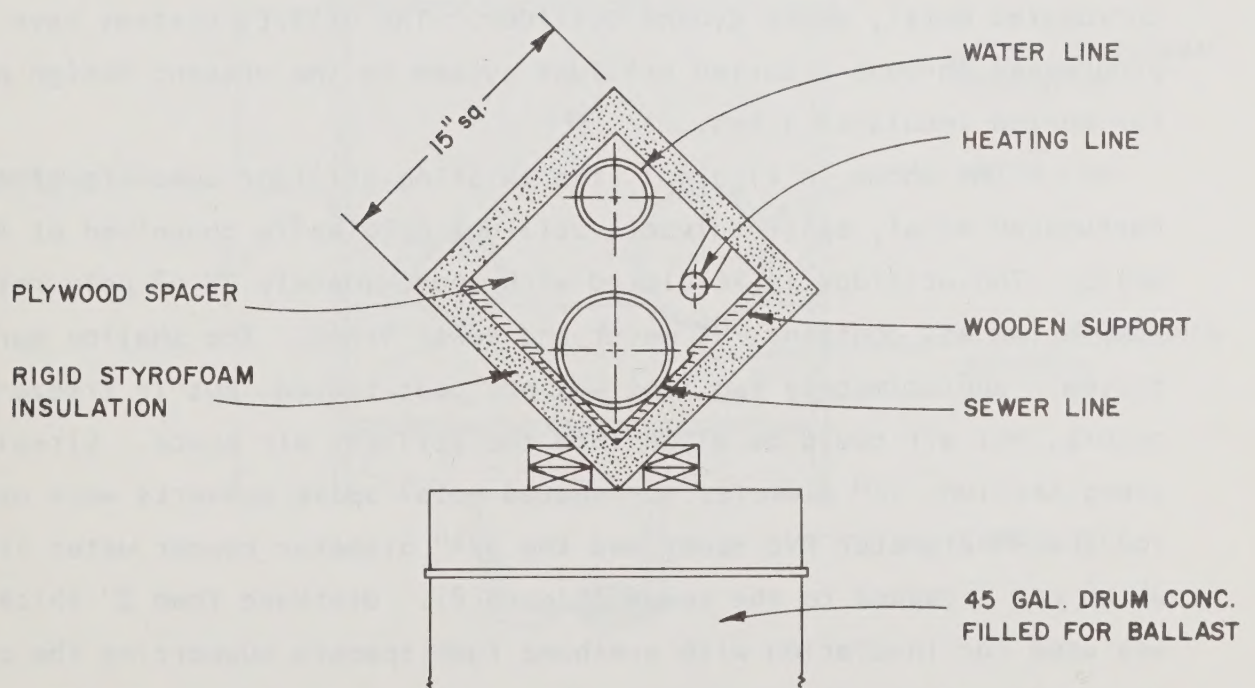
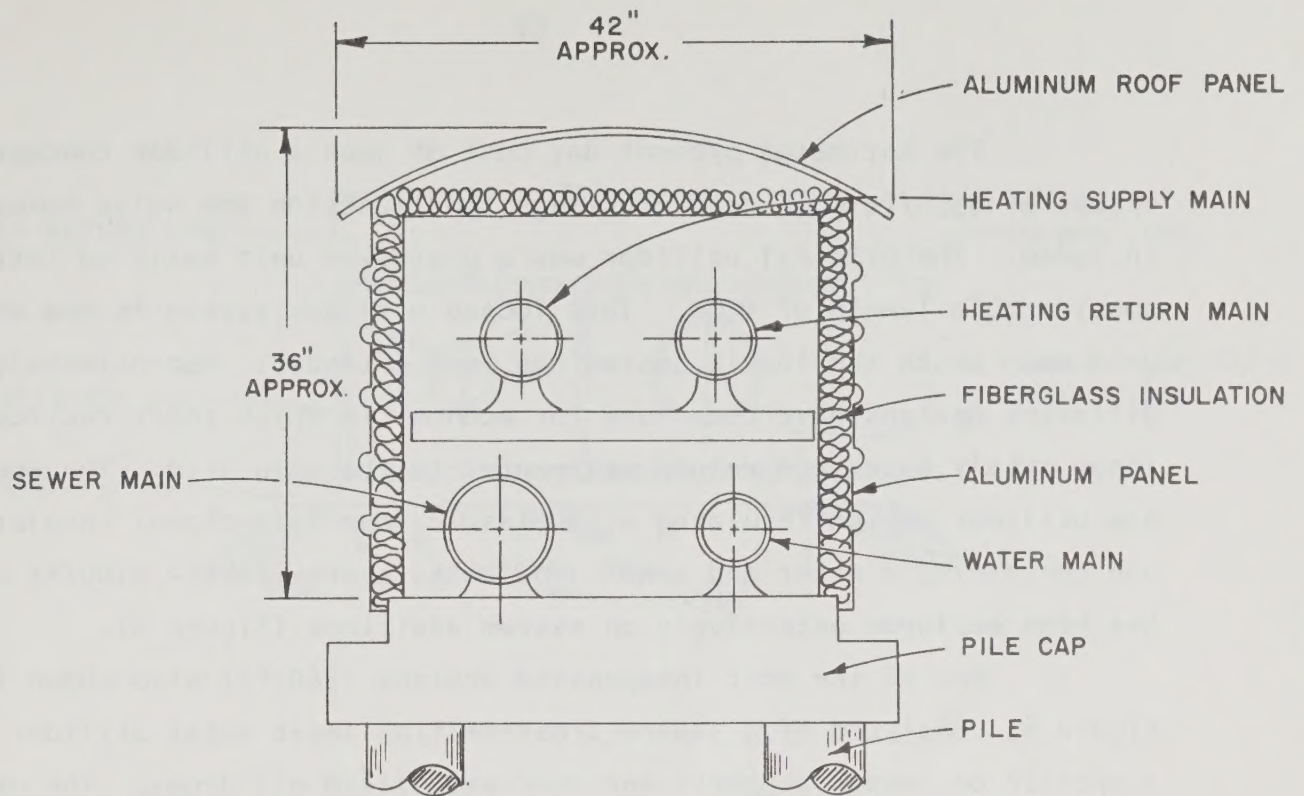


FIGURE 5. CROSS SECTIONS OF ORIGINAL UTILIDOR AT INUVIK AND MODIFIED ECONO UTILIDOR

The estimated present day cost of such a utilidor concept is in excess of \$350/ft when road crossings, and junction and valve boxes are included. The original utilidor was a prototype unit built to last a considerable length of time. This looped utilidor system is the supply grid upon which the Inuvik system has been extended. Approximately eight different designs have been used for economy in which short recirculating loops supply water and return wastewater to the main grid. The wood box utilidor design insulated with plastic foam (styrofoam) insulation and containing a water and sewer line costs approximately \$180/ft and has been employed extensively on system additions (Figure 6).

One of the most inexpensive designs (\$60/ft) also shown in Figure 6, consisted of a square cross-section sheet metal utilidor supported on wooden supports and concrete filled oil drums. The utilidor contained sewer and water lines, and small diameter high temperature water lines; it was insulated with rigid styrofoam insulation. Relatively unskilled labour was used for the construction and because of fabrication mistakes the system lasted only three years.

Rankin Inlet, N.W.T.

This town originally used a piped system comprised of a corrugated metal, above ground utilidor. The utility systems have progressed through a buried utilidor system to the present design plans for buried insulated lines.

As shown in Figure 7, the existing utilidor consists of the corrugated metal, split-culvert, utilidor originally conceived at Norman Wells. The utilidor is insulated with approximately 2" of polyurethane insulation and contains PVC water and sewer lines. The shallow buried system - approximately two feet was not heat traced, but if freeze-up occurs, hot air could be blown into the utilidor air space. Circular cross section, 12" diameter corrugated metal split culverts were used for the 4" diameter PVC sewer and the 3/4" diameter copper water line which was strapped to the sewer (Figure 8). Urethane foam 2" thick was used for insulation with urethane foam spacers supporting the pipes internally within the utilidor. The service connections were heat traced with 2½ watt per foot thermostatically controlled electrical heating cables.

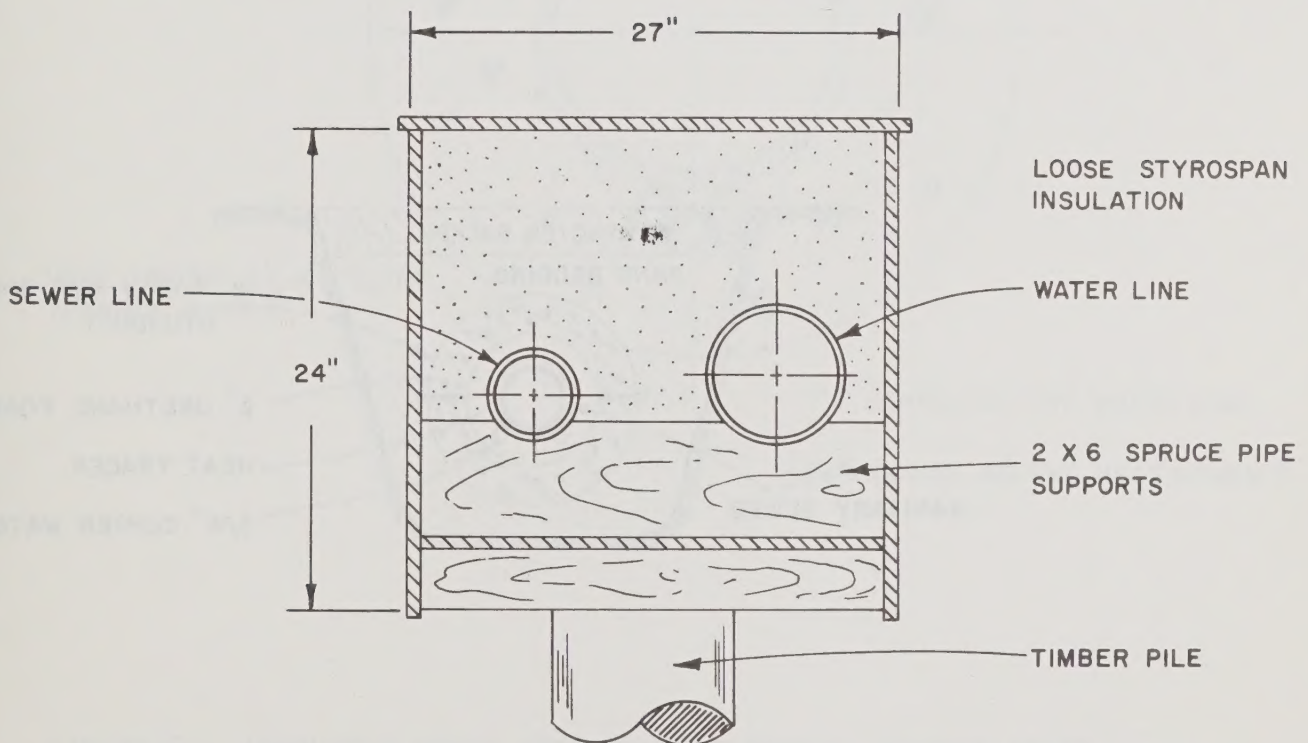
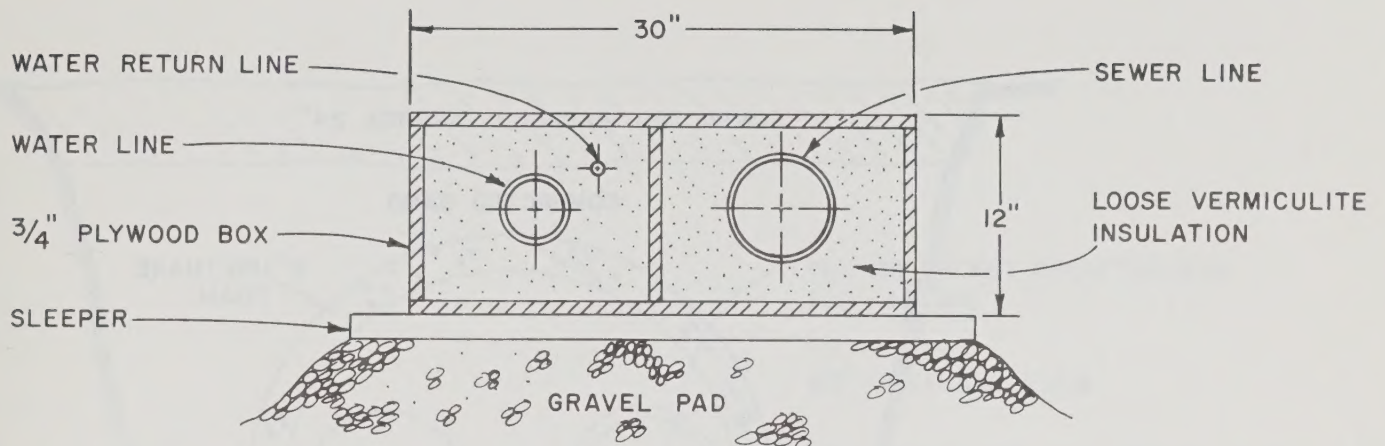


FIGURE 6. CROSS SECTIONS OF WOOD BOX UTILIDOR ON FILL AND ON PILES

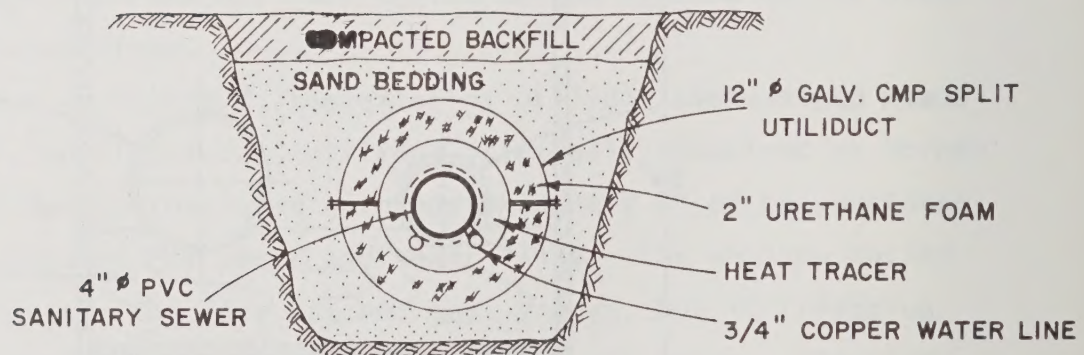
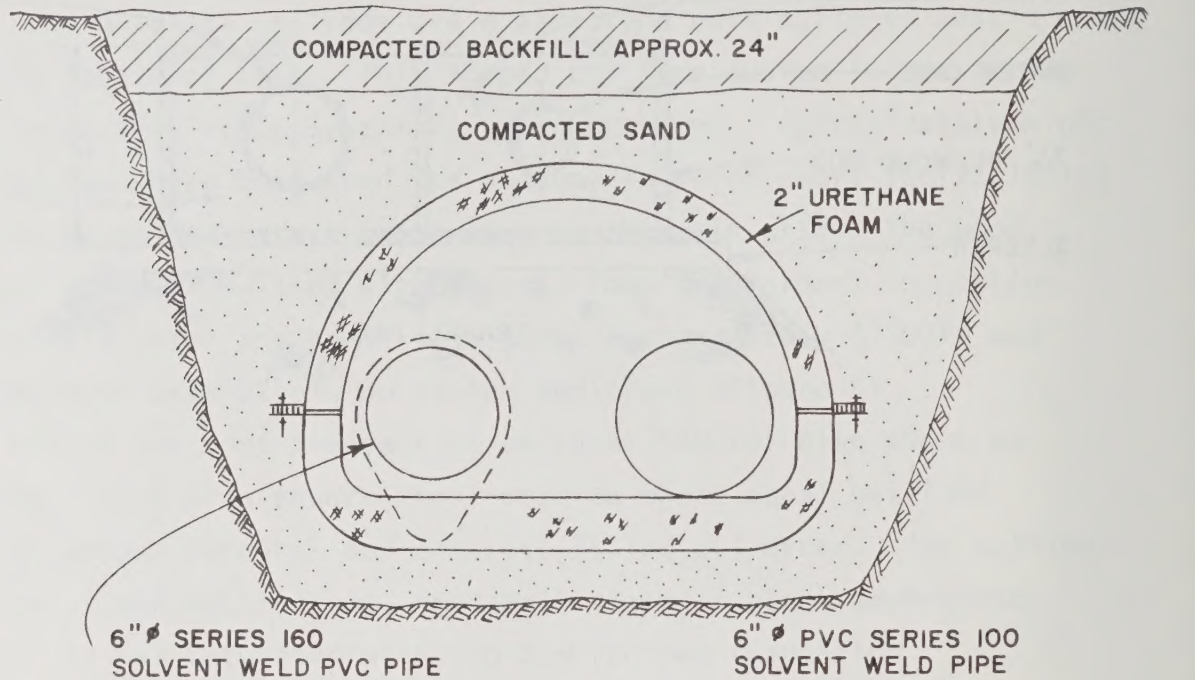


FIGURE 7. RANKIN INLET BURIED UTILIDOR

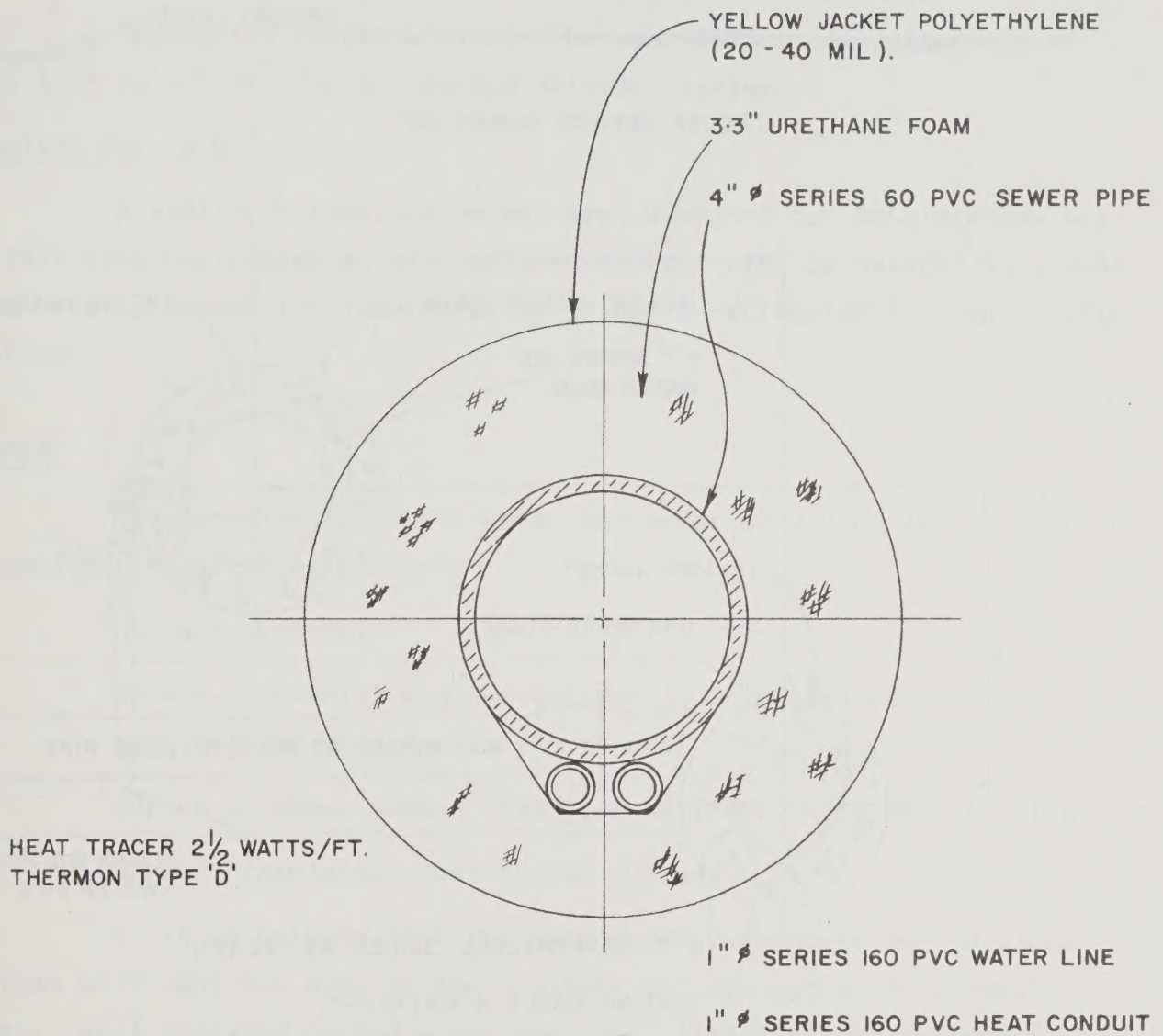


FIGURE 8. INSULATED HOUSE SERVICE PIPE BUNDLE, RANKIN INLET

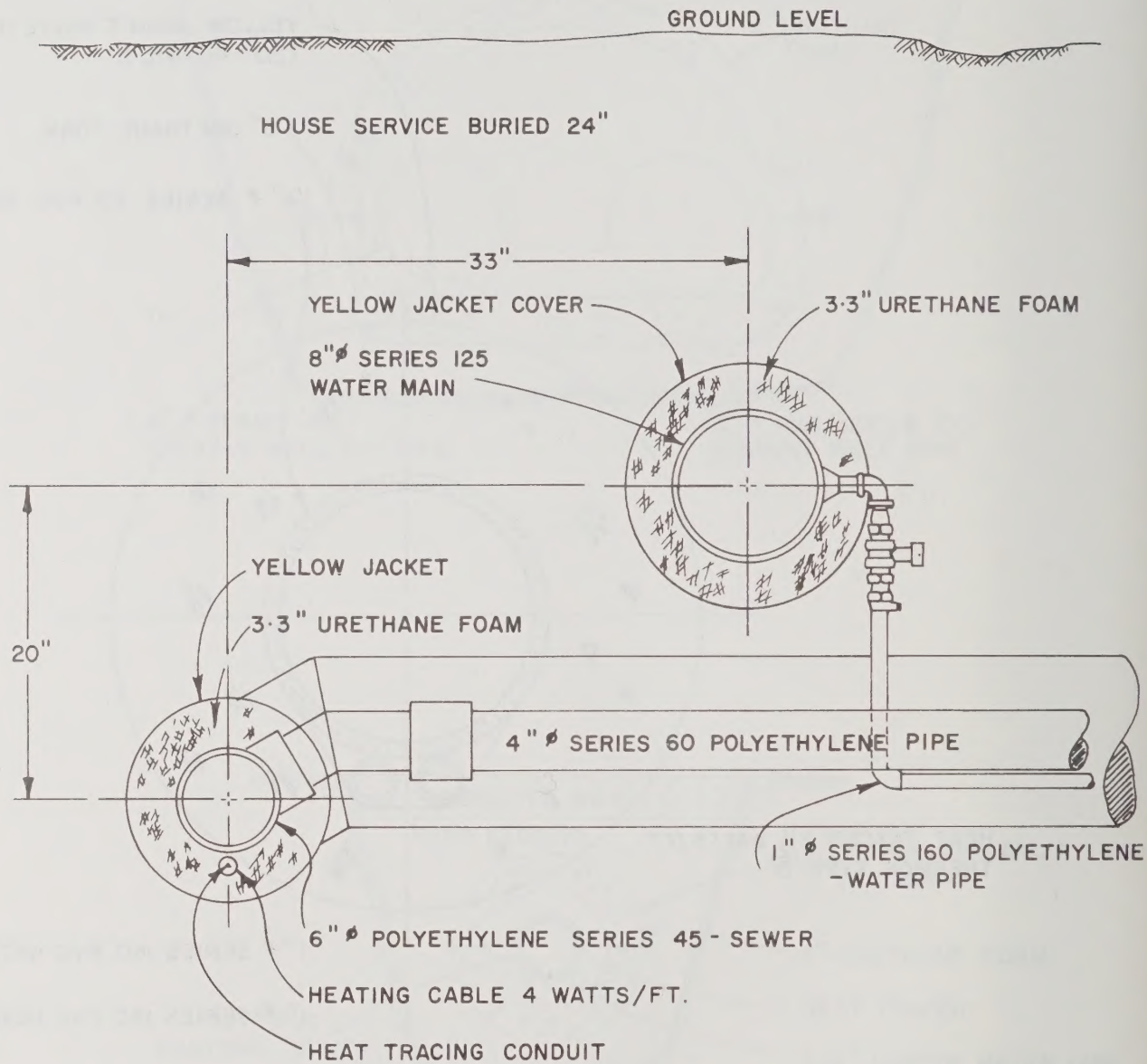


FIGURE 9. SECTION - HOUSE SERVICE, RANKIN INLET - NEW SYSTEM

A new design has been prepared for the extension to the system consisting of buried insulated, polyethylene water and sewer pipes as shown in Figure 9. The urethane insulated lines will be buried in the same trench and traced with thermostatically controlled 4 watts/ft electrical heating cables. To prevent water penetration of the insulation, the system is covered with a polyethylene film.

The buried system will cost between \$120 to \$140/ft compared with \$160 to \$180/ft for the buried utilidor system.

Resolute Bay, N.W.T.

A similar buried system has been designed for Resolute Bay but in this case recirculation of water in services will be assured by a dual line service connection incorporating either a recirculation pump or pit orifices.

SUMMARY

The Canadian trend for water and sewer servicing in far northern communities has been as follows:

- 1) haulage systems;
- 2) buried, uninsulated piped systems in which heated water is recirculated and bled to the sewers;
- 3) buried or above ground insulated utilidors with heat tracing; and,
- 4) buried, insulated, heat traced systems.

It is my opinion that the demand for dependable buried piped systems will continue even in the smallest of communities in Canada's North. Well designed buried water and sewer lines will be the most popular form of water utility delivery practised.

UTILITIES DELIVERY IN ARCTIC REGIONS
EARLY DEVELOPMENT IN ALASKA

by

Amos J. Alter
Alaska Department of Environmental Conservation

Communication lines (water mains, sewers, service connections or other facilities or means used to transport water or wastewater) of many kinds have been used in Alaska. Early utility service was simple; it was an individual concern [1]. Developments from simple service of legendary beginning have grown into historical example [2], and contemporary practice [3, 4]. Future utility service will reflect the benefits from experience with past developments to a greater or lesser degree depending upon the significance attached to these experiences. The intent of this over-view of early developments in Alaska is to provide a background which will assist in projections for the future.

Contemporary utility service differs much from aboriginal communication lines [5]. Legendary practice conformed with individual preference [6, 7, 8]. In some limited ways individual preference was subjected to group welfare, but not for the purpose of providing communication lines. Individuals only worked cooperatively for certain over-riding purposes such as in obtaining food and clothing. Harsh arctic conditions (Figure 1) required cooperative action to this extent.

In contrast with the situation in which aboriginal cultures live in a society almost devoid of corporate community structure, persons who have arrived relatively recently in the North expect central government to meet every need [9]. The anomaly which exists in Alaska, in which different cultures each with its own "frame of reference" strive to establish and maintain a twentieth century life-style in some way foreign to all, has produced some interesting results [10]. Almost everyone in Alaska is experimenting either with a new life-style in an old and familiar country or an old life-style in a new and unfamiliar country. Developments in water supply and waste disposal services reflect this uncertain blend of the old and the new as well as attest to the ambivalent role of government as either or both provider and mechanism for aiding the individual to provide for his own needs [11].

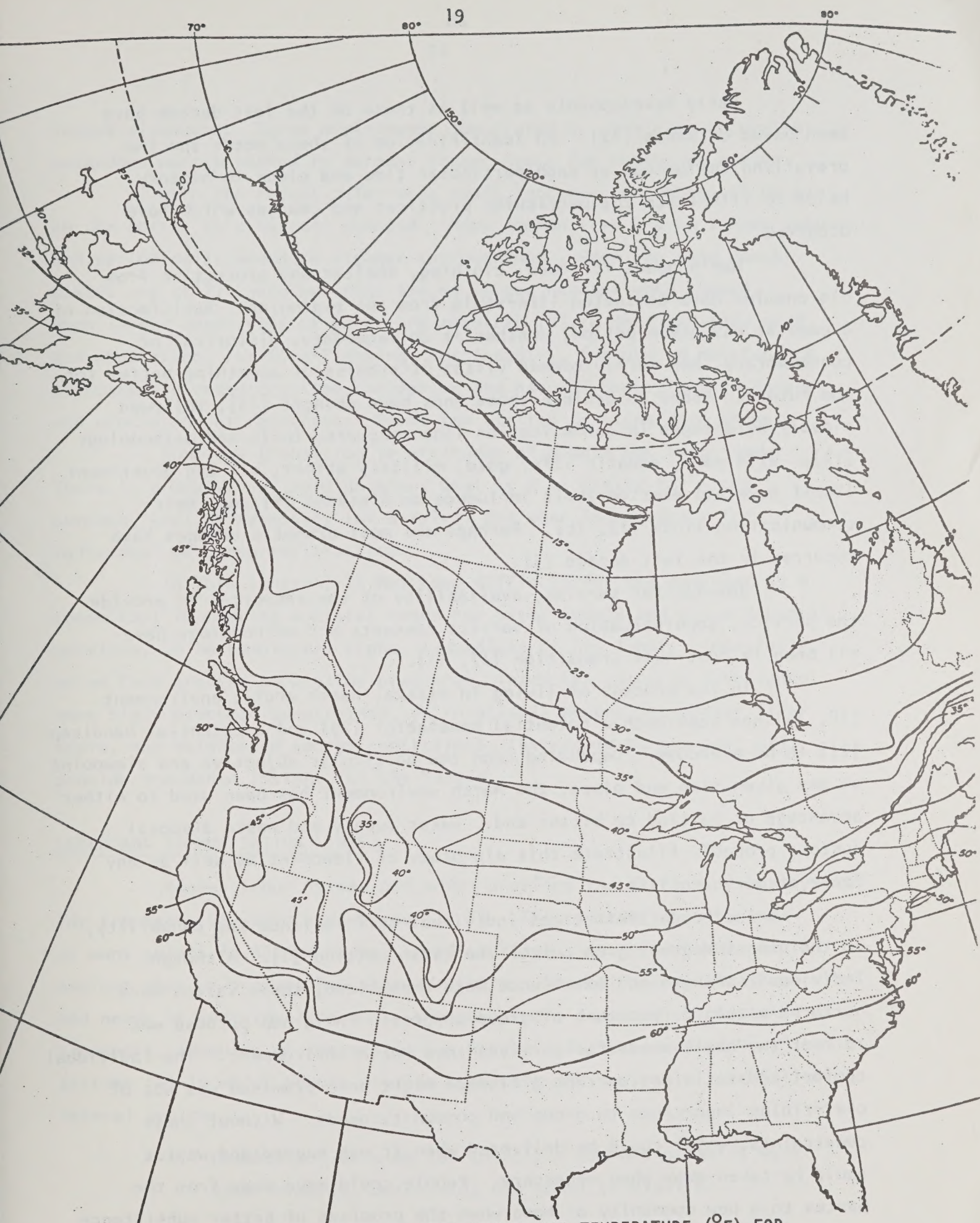


FIGURE 1. ISOTHERMAL CHART OF MEAN ANNUAL AIR TEMPERATURE ($^{\circ}\text{F}$) FOR ALASKA, CANADA AND CONTIGUOUS UNITED STATES

Early developments as well as those of the last decade have been based on needs [12]. An identification of these needs and the prevailing influences at each particular time and place in history helps to illuminate the particular practices and changes which have occurred.

Man's needs for food, clothing, shelter and protection from his enemies have dominated life-style from the beginning. Satisfaction of a need at any given period, whether it be legendary, historical or contemporary, has merely opened vistas of promise of something better for the future. Means to achieve those ends have changed [13], followed closely by changes in communication line concepts, tools and methodology [14]. Wild game, aquatic life, gold, military effort, oil and government itself have all exerted their influence on Alaskans [9] and their communication lines [15, 16]. Perhaps the most dramatic changes have occurred in the last decade [5].

Demands for service, availability of the resources to provide the service, sophistication of service concepts and methodology have all been in continual transition [17, 11].

In the process of living in Alaska, harsh arctic environment [18, 19] has been both a potential benefactor [20] and a potential handicap [21] to be overcome. Depending upon the particular objective and viewpoint at any given time and place, the harsh environment has been used to either advantage or battled to bitter end. Water supply and waste disposal customs probably illustrate this dichotomy of viewpoint as well as any facet of northern life.

In the earliest times individual self reliance and capability, to the utmost degree, grew out of the harsh setting [1]. Although individual strength and excellence were emphasized, these values were nurtured within a framework of group purpose. The group purpose was to meet the basic needs for survival in a harsh environment. The individual comfort and satisfaction that affluence might have promised was not of over-riding importance to group and community needs. Without these constraints, water could be delivered when it was needed and wastes could be taken away when necessary. People could move away from the wastes to a new community or home when the promises of better subsistence

loomed elsewhere. Harsh environment cooperated by retaining otherwise hazardous wastes locked in dormant frozen state for months at a time.

With the recent relatively rapid increase in numbers of people in the north, this has all changed. Many communities are no longer temporary and periodically moved to cleaner surroundings. When the thaw comes wastes are still there but they are no longer dormant when thawed. Much larger quantities of water are required [3] to meet expanded need and population, for fire-fighting, for industry, for use in maintenance of renewable resources, for recreation and natural beauty and in harvest and processing of resources. Needs for utility services have grown.

Complete transition in attitudes of people has been slower. There is a mixture of opinion about what is a necessity for group purpose, what is necessary for survival and what is necessary for individual or group satisfaction.

In this context, it has been difficult for the engineer as a consultant in meeting societal needs for water supply and waste disposal services, to be completely right, regardless of his labors. Hopefully, as we face greater population pressures, intensive resource development, more rigid economic constraints, an insatiable hunger for better life-style, and heightened energy constraints, the record of the past will provide broadened insight for the future.

LEGENDARY COMMUNICATION LINES

Manual labor by men and women provided the first delivery system for transport of water and wastes [1, 7]. This system is still used at many points in Alaska today. Hand-carriage transport whether in the ancient past or present has changed little. Depending upon the whims and needs of individual persons, the containers used and the distance of transport, adequacy of the system has varied. These so-called "dry" systems [4] in which people provide transport may use any of the following several devices:

1. Chamber pot or slop jar (possibly baskets or skins were used formerly, porcelain; now metal or plastic).
2. Cabinet and chamber pot (commode, box and can, cabinet and pail) etc.

3. Chemical toilet with removable receptacle (deodorant powder or solution may or may not be added).
4. Metal cabinet and bag-type receptacle (fitted with plastic or paper bags).
5. Folding metal frame fitted with molded seat (for use with disposable bags).
6. Latrine (pit for direct use by individuals or receipt of residues).
7. Privy (small building with bench for seat and holes through the seat for user).
8. Improved privy (basic unit is improved by use of porcelain, metal, concrete, or plastic riser instead of bench; a molded seat is used).
9. Improved privy with burning pit (pit for periodic burning of waste).
10. Chemical toilet-privy type (wastes drop into large charged holding tank; a mixture of strong alkali and water digests wastes into a slurry; pumping equipment is required to remove slurry for hauling to point of discharge).
11. Incinerator toilet (wastes are fired in commode unit; vent required; firing may be with electricity, gas or fuel oil as a source of energy).
12. Receptacle for collection and composting wastes within house (vent required).

Water is carried as ice or as water and stored in small quantities at the home [3]. Ice may be collected in sufficient quantity to last the entire winter and stored outside near the home or in a permafrost cellar. The euphemistic chamber pot is kept in the home until filled; it may be emptied periodically or emptied after each use. Figure 2 shows a typical, village water hole and waste barrel, water supply and waste system.

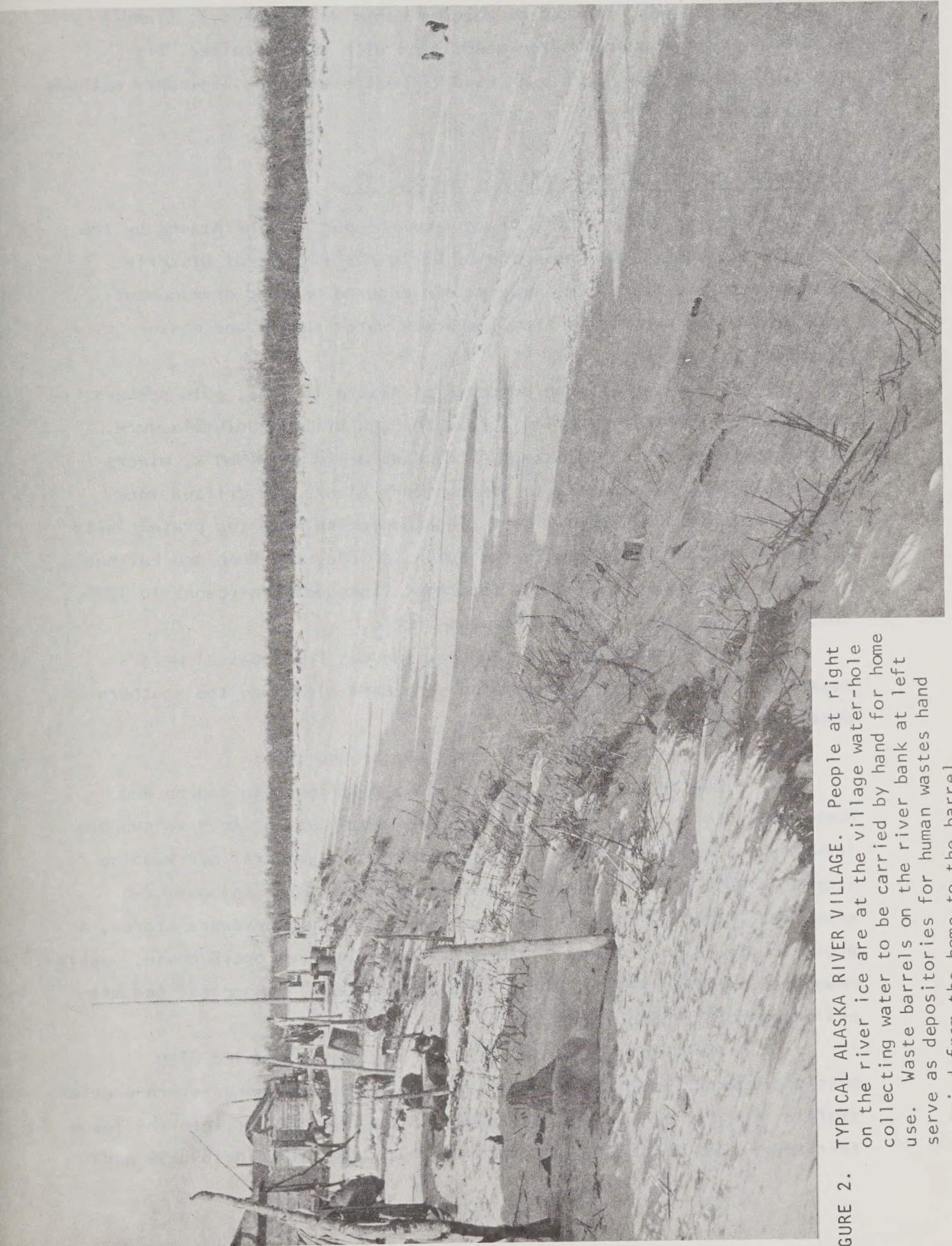


FIGURE 2. TYPICAL ALASKA RIVER VILLAGE. People at right on the river ice are at the village water-hole collecting water to be carried by hand for home use. Waste barrels on the river bank at left serve as depositories for human wastes hand carried from the home to the barrel.

Dog sleds, tracked or wheeled vehicles (Figures 3, 4 and 5 illustrate appurtenances often associated with the so-called "Dry System") and aircraft have been used to modernize these legendary methods for transport.

HISTORICAL COMMUNICATION LINES [2, 9, 13, 22]

During the period of time from the purchase of Alaska by the United States until the beginning of World War II several historic developments occurred. The impetus of resource use and development triggered a few departures from legendary water supply and waste transport practice.

At the time of the purchase of Alaska in 1867, gold seekers moving north and west from California through British Columbia were making their entry into Alaska. After Cassiar in the 1860's, miners found gold in small amounts in Southeastern Alaska and drifted into Sitka in the 1870's. Significant finds beginning near the present site of Juneau in 1880, Klondike in the Yukon in 1896, the Nome and Fairbanks areas in 1900 and Felix Pedro's important finds near Fairbanks in 1903, scattered gold seekers across the sub-arctic.

Exploitation of rich salmon resources from coastal waters began in 1878 and within two decades stretched all along the southern coasts of Alaska.

Coal mining began in a small way around 1906.

Sitka began to grow again and communities like Juneau and Nome came into being with real needs for communication lines to support industry and community life. Juneau boasted nine general merchandise stores in 1890 and three hotels, a lodging house, nine saloons, two breweries, two drug stores, two cigar factories, two hardware stores, a photo studio, a confectionery store, a steam laundry, opera house, weekly newspaper, millinery shop, three schools, churches, a hospital and miscellaneous other enterprises.

Activity on the gravel bars of the Yukon, coupled with missionary work, and hunting and trapping, supported summer stern-wheeler traffic from St. Michaels at the mouth of the Yukon River into the Yukon territory. The White Pass and Yukon Railway was built in 1898-99 and

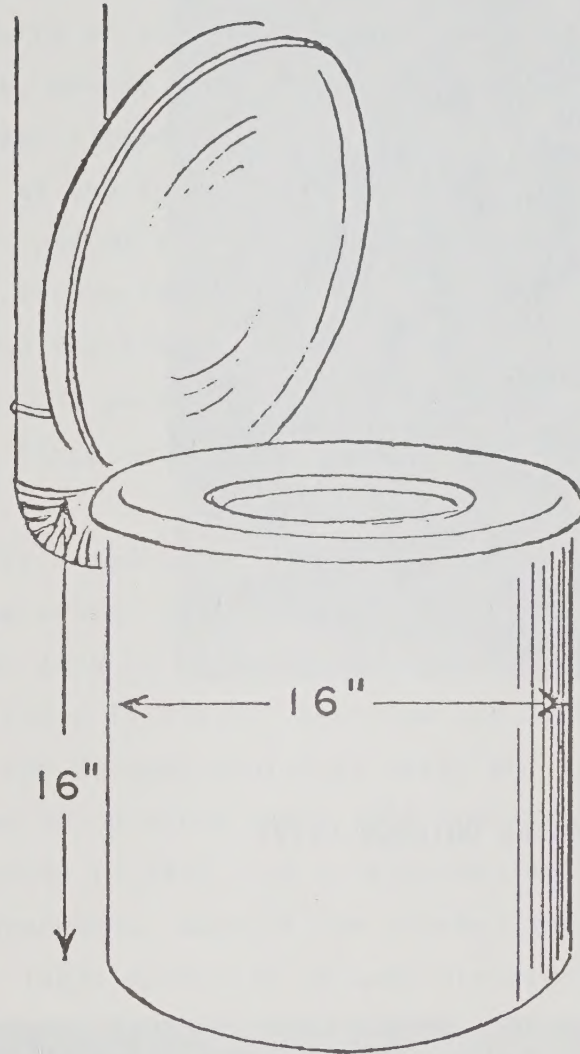


FIGURE 3. TYPICAL INDOOR RECEPTACLE FOR HUMAN WASTE.
Bucket inside of seat is hand-carried to a point of discharge.



FIGURE 4. ALASKAN OUTDOOR PRIVY

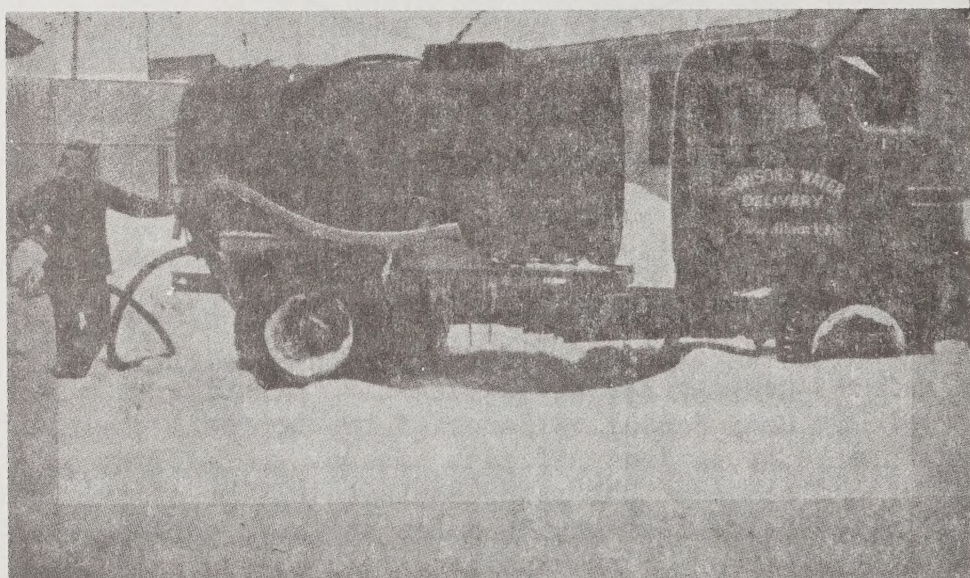


FIGURE 5. WATER DISTRIBUTION BY TANK TRUCK

vessel traffic up the inside passage and to the Bering Sea was vigorous. A network of trails had sprung up linking the upper end of the inside passage to the Klondike, the Valdez area to the interior, and the interior to Seward Peninsula and Nome. Yukon River and coastal steamers plied what became busy transportation corridors.

This flurry of activity produced numerous water and waste transmission works, mostly gravity flow systems, with miles of wooden flume, both open and closed wooden pipe, and even open earthen and rock ditches such as the famous Treadwell Ditch which in its day conveyed water for use at the 880 stamp Treadwell, the biggest gold mill in the world in the late nineties. Fish processing at the seasonally operated facilities required tremendous amounts of water. These systems, as well as water systems for mining operations, no doubt brought about the first seasonally operated water supply and distribution works.

Privately owned water works in the Sitka, Douglas and Juneau areas began providing water for limited public use soon after discovery of gold in the Juneau area in 1880. Congressional tardiness in authorizing municipal corporations in Alaska, taxation and bonding authority necessary for community action delayed municipal water and sewer construction. Such authority was not granted until 1899 and then it was limited. Although statehood was granted in 1959, and provisions were subsequently made for local, borough government, much of the unorganized borough is still without effective legal mechanism to meet areawide utility needs. Bonding authorization under the 1899 federal act was not to exceed 1% of property values. Even in those days, with this limitation little could be done in providing needed water supply and sewerage. Consequently, significant municipal projects did not develop until the period 1916-1930 when water and sewerage work was included in congressional bond authorizations for Wrangell (\$80,000), Juneau (\$60,000), Cordova (\$50,000), and Ketchikan (\$1,000,000). Ketchikan voters authorized purchase of the private Foshay Company in 1930 and established the earliest fully municipally owned modern public utilities system in Alaska.

Law and order, to a degree, followed this bustling interest in Alaska and with it the need for water and waste facilities for government

posts. The War Department, through "The Department of Alaska" with headquarters at St. Michaels, built forts along routes travelled by prospectors. Fort David (near Nome), Fort Gibbon (Junction Tanana and Yukon), Fort Egbert (Eagle), Fort Liscum (Valdez) and Fort Seward (near Haines), were established around the turn of the century. Perhaps through this effort some of the first attempts were made at artificially heating water transmission lines.

Problems of frazil-ice in intakes, freezing of water transmission works and all the hazards of frost susceptible transmission works plagued these early systems (Figure 6). Fires were built to heat water (Figure 7) and even the sophistication of a stationary steam boiler was added to some systems to keep water flowing. Wooden flumes and pipe provided some insulation qualities to the transmission works in that they did not transfer heat as rapidly as the riveted steel pipes used so commonly in early industrial works.

With the consolidation of many smaller placer gold mining efforts in the interior and Seward Peninsula regions of Alaska into large centralized operations in the mid 1920's [9], there were new demands for industrial water supply and waste discharge works. Hydraulicking and dredging became big business. The success of this business was dependent upon being able to transport and to use large quantities of water and to move large quantities of waste materials to a point of discharge. Cold water thawing techniques [12] used to remove, overburden and to prepare the gold bearing sediments for dredging were entirely dependent upon water supply. As many as forty large dredges operated throughout interior and Seward Peninsula Alaska during the heyday of dredging [22] and each was dependent upon large quantities of water. Impoundments of water on frozen terrain [23] were done successfully with earth fill dams and diversion techniques were used which contributed much to current understanding of the problems of providing communication lines under low temperature conditions [3]. A large diameter 76 mile-long gravity pipeline brought water from the Chatanika River to operations near Fairbanks [23]. This line passed through permafrost areas, across hills and valleys and employed the first large diameter

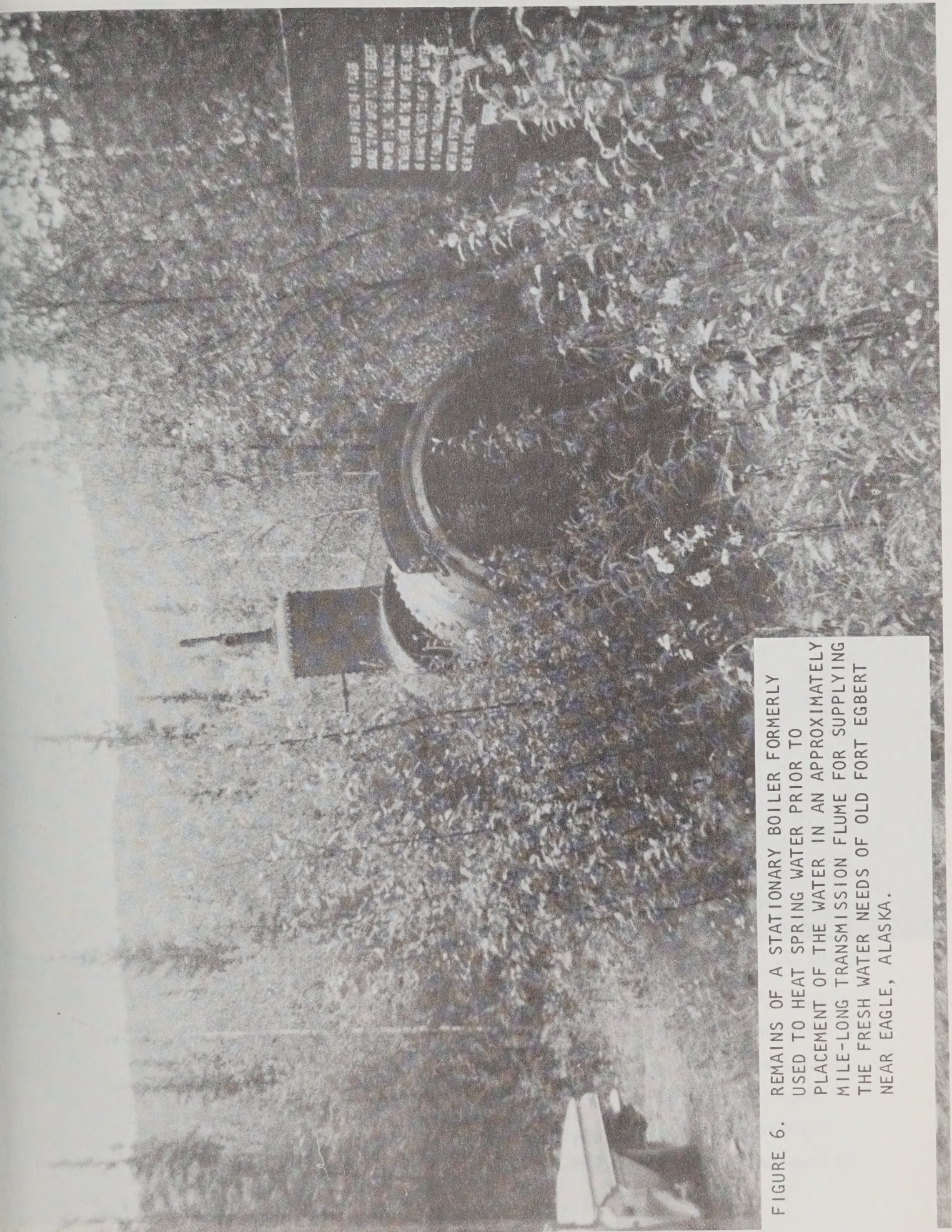


FIGURE 6. REMAINS OF A STATIONARY BOILER FORMERLY USED TO HEAT SPRING WATER PRIOR TO PLACEMENT OF THE WATER IN AN APPROXIMATELY MILE-LONG TRANSMISSION FLUME FOR SUPPLYING THE FRESH WATER NEEDS OF OLD FORT EGBERT NEAR EAGLE, ALASKA.



FIGURE 7. REMAINS OF ONE OF SEVERAL BUILDINGS USED AT WAY POINTS ALONG THE FLUME TRANSPORTING SPRING WATER FOR USE AT FORT EGBERT. The flume passed through a metal section suspended high enough above the floor in the building that a fire could be built under the metal section of the flume to heat the water and thereby keep it from freezing on its way to the Fort.

hydraulic siphon in use in Alaska [15]. Because of cold stress it was necessary to operate the system on a seasonal basis. Knowledge of cold weather problems of water supply and waste disposal was bolstered more perhaps by large hydraulicking efforts than in any other way up to that time.

During the period from 1880 to 1944 mining interests were consolidated in the Juneau area [9]. Although it closed in 1944, at its peak, the Alaska-Juneau enterprise was the world's largest low-grade ore gold mining venture. This mammoth operation used water for hydro-power and for milling operations. Impoundments at Salmon Creek (the highest concrete arch dam in existence at the time it was build), Nugget Creek and a "lake tap" diversion at Annex Creek, as well as a network of flumes and penstocks taking water from Salmon, Nugget, Gold and Annex Creeks, among others, used millions of gallons of water each day in meeting industrial and community needs [24]. These operations also contributed to the storehouse of knowledge and experience in the problems of collecting and transporting water and wastes [25].

At one time Alaska gold production constituted almost half of the nation's annual production and the success of the industry was largely based on the ability to transport copious amounts of water to and from the point of need.

With the advent of depression-triggered federal public works programs into Alaska in the mid-1930's, several community water supply and waste disposal systems were built [22]. The Fairbanks municipal sewer system was the first full-scale community sewerage project built in the permafrost region of Alaska [22]. Built under telescoped schedules of the federal program, temperate climate concepts and design were used. In a report by the city engineer of Fairbanks in the late 1940's this system was reported to have cost more to maintain than it cost to build [22]. Freezing problems plagued the operation. Many relatively short laterals on minimum grades enhanced freezing problems [26]. The only unusual features, incorporated into the system to provide better adaptability to operation in permafrost, were construction with wood-stave pipe and use of wood-stave pipe manholes. Heat from cold groundwater was used later as an ingenious device for minimizing sewer freezing [3].

Steam thawing techniques were vastly improved through Fairbanks' experience in winter maintenance and operation [15].

As a corollary, perhaps the public experience with the Fairbanks system contributed to extreme lethargy in providing the community with a water system. A community water system, other than the small utilidor system serving a very limited downtown section of the city, was not built until 1952.

The first use of utilidors in Alaska to protect communication lines from freezing in the early 1900's appears to be those installed by predecessors of the Northern Commercial Company (Alaska Commercial Company) at Fairbanks. Steam heat and water for fire protection were made available to company properties and in a limited section of the downtown business portion of the city. The utilidors, buried and rectangular in cross-section, were constructed of wood planks and provided similarly constructed ducts for service connections to the facilities to be served and a few ducts for street hydrants at street grade for fire fighting [27].

Several smaller water and sewer projects were built under direction of the U.S. Forest Service and with use of national recovery work programs (Works Progress Administration, Civilian Conservation Corps, etc.). Saxman, Klawock, Hydaburg, Angoon, Sitka, Douglas, Wrangell, Petersburg, Skagway, Haines and Klukwan all received federal Works Progress Administration assistance to improve water systems [22]. These systems were all dependent upon sufficient quantities of water flowing to waste through the system to keep them from freezing, with the exception of the protection provided by use of wood stave pipe in the communication lines. Sewers under this program were mostly for the use of native schools operated by the Federal Bureau of Indian Affairs. Wood stave pipe was also used for the sewers but this pipe apparently was not pressure treated to properly protect it for use as a sewer.

Matanuska Colony was settled in 1935 under auspices of the federal government through the Federal Emergency Relief Administration with assistance from several other federal and territorial agencies [9]. Community water supply and sewage disposal facilities were built for the

new community, Palmer. A sewage treatment plant, an Imhoff tank, built for treatment of domestic wastes from Palmer was possibly the first community sewage treatment plant in Alaska [22]. A second and similar plant was built about the same time at the University of Alaska at Fairbanks to treat wastes from the Eielson Building and other later buildings. Sewage treatment plants at military posts were next but did not follow until four or five years later. The Palmer facility, as well as some of the other plants, were housed in wood frame structures to protect them from freezing. No additional heat was provided for the Palmer and University plants.

Following a modified practice, first reported in Alaska at the Pullen House in Skagway [22] shortly after the turn of the twentieth century, water lines for the new Palmer water system were protected from freezing by placing them above and partially inside the sewerage. Two inch galvanized water lines in the Palmer system were laid immediately above the sewers but run through sewer manholes. In contrast, at the Pullen House the iron water lines were continuously submerged in sewage by placing them on the invert of the sewer and in the bottom of a continuously flowing creek at points where there was no sewer. Although both practices leave much to be desired and give public health people "nightmares", the Pullen House system was not so readily corroded by environmental elements as was the Palmer system. Alternate wet and dry environment and corrosive gases and wastes from the sewage in the manholes soon made the Palmer water lines leak. Corrosion at the manholes was later reported to be so severe that when a fire engine pumping unit which exceeded the capacity of the water lines was connected to the water system, the water lines actually collapsed in some of the sewer manholes [22].

CONTEMPORARY COMMUNICATIONS LINES

Beginning with the buildup in Alaska in preparation for World War II, broad scale departures in communication line practice took place. An extensive utilidor system enclosing water, sewer, steam and other service lines was built at Ladd Field constructed near Fairbanks [27].

This construction, which began in the late 1930's and continued sporadically until the end of the 1950's, also included two sewage treatment plants and extensive sewerage [15]. The utilidors were built in large cross-section and placed in the ground to serve as protected passage ways for personnel as well as utilities (Figure 8). Later utilidors, although greater in length, were of much smaller size in cross-section. Many parts of the later systems were constructed with removable concrete slab covers to facilitate maintenance (Figure 9). Tops on the older utilidors served as both top for the utilidor and concrete slab sidewalk. Waste heat from the utilidors melted accumulations of snow on the walk. Typical utilidor construction is shown in Figures 11, 12, 13 and 14.

Wood frame construction was used to provide an extensive utilidor system at nearby Eielson (Mile 26) Field (Figure 10). These utilidors did not provide the luxury or the utility that was provided by utilidors at Ladd Field. They were soon filled with groundwater and became difficult to maintain.

Water systems and sewerage were installed at several points throughout Alaska (Aleutian Islands, Barrow, Seward Peninsula, Anchorage area, Cordova, Yakutat, Kodiak Island, Seward, Sitka, Excursion Inlet, Juneau, Skagway, Haines, Gustavus, Annette Island, and Ketchikan*). Most of the construction at these places, with the exception of Barrow, was of almost conventional type. Exceptions were distribution of water through wood-stave pipe and collection and transport of sewage in mostly wood-stave pipe. Sewage treatment was mostly by septic or Imhoff type tanks built to standard military specifications.

Operational experience showed that these facilities served their immediate purpose but, except for the utilidor systems and those systems on the warmer southern coasts, malfunction was the rule rather than the exception [29, 39, 31, 32]. The very limited facilities at Barrow functioned, but in this case the communication lines were provided mostly through manpower and vehicle rather than through piped systems.

*The system and treatment plant to supply water for the airfield on Annette Island near Ketchikan was perhaps the first surface water system to include a rapid sand filter plant for color removal after coagulation and settling. Facilities at Ladd Field included provision for iron removal from water supplied from wells [28].

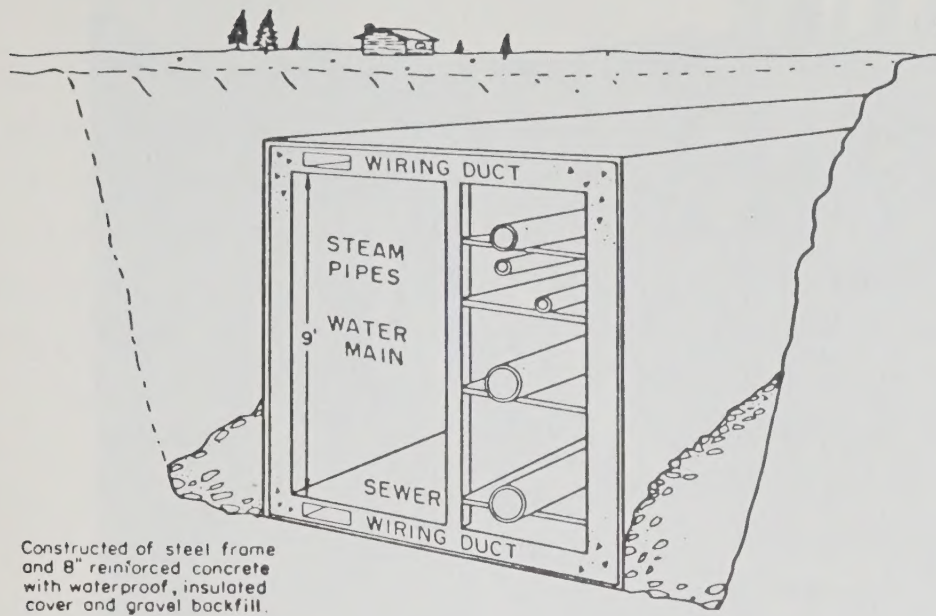


FIGURE 8. WALK-THROUGH UTILIDOR, 7 ft by 9 ft

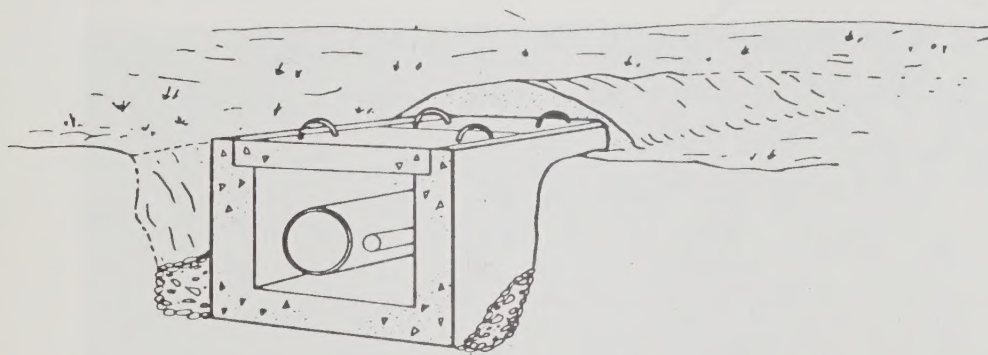


FIGURE 9. REMOVABLE TOP ON CAST-IN-PLACE CONCRETE UTILIDOR

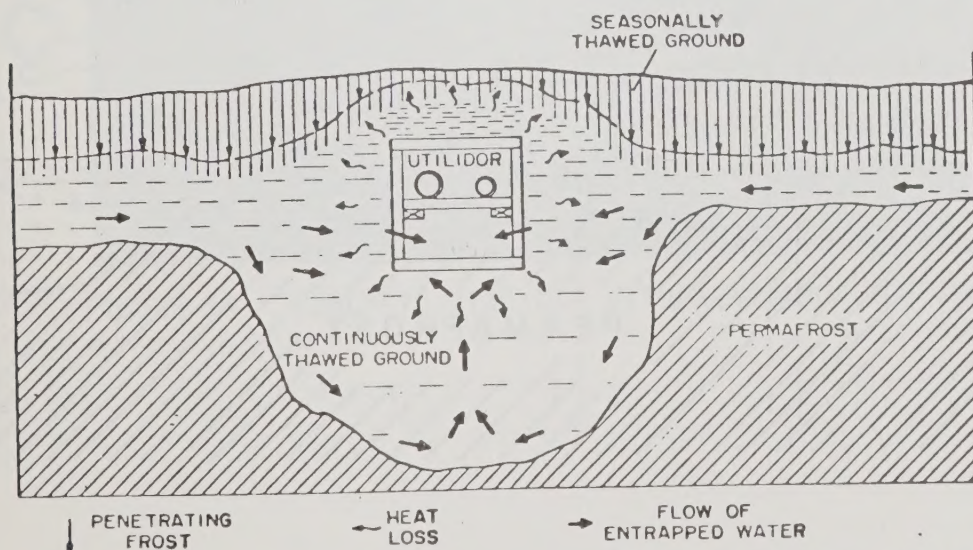


FIGURE 10. DRAINAGE OF ENTRAPPED WATER INTO IMPROPERLY SEALED UTILIDOR

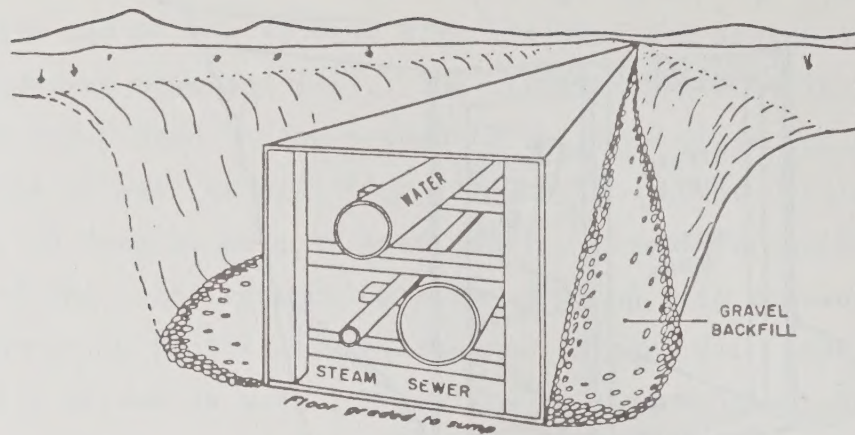


FIGURE 11. SMALL UNDERGROUND WOOD UTILIDOR

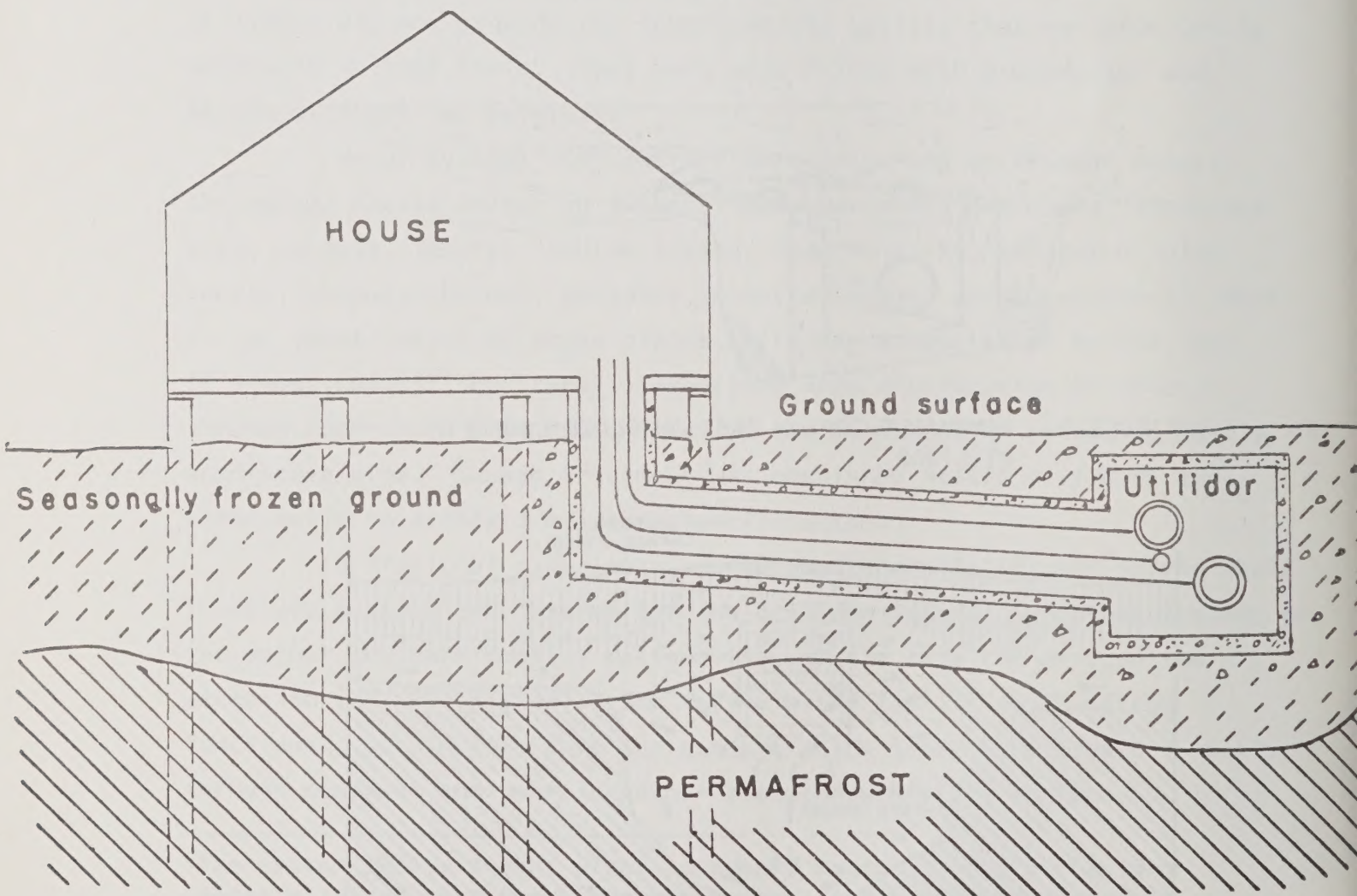


FIGURE 12. TYPICAL SERVICE CONNECTION FOR SMALL UNDERGROUND UTILIDOR



FIGURE 13. TYPICAL CONCRETE UTILIDOR UNDER CONSTRUCTION

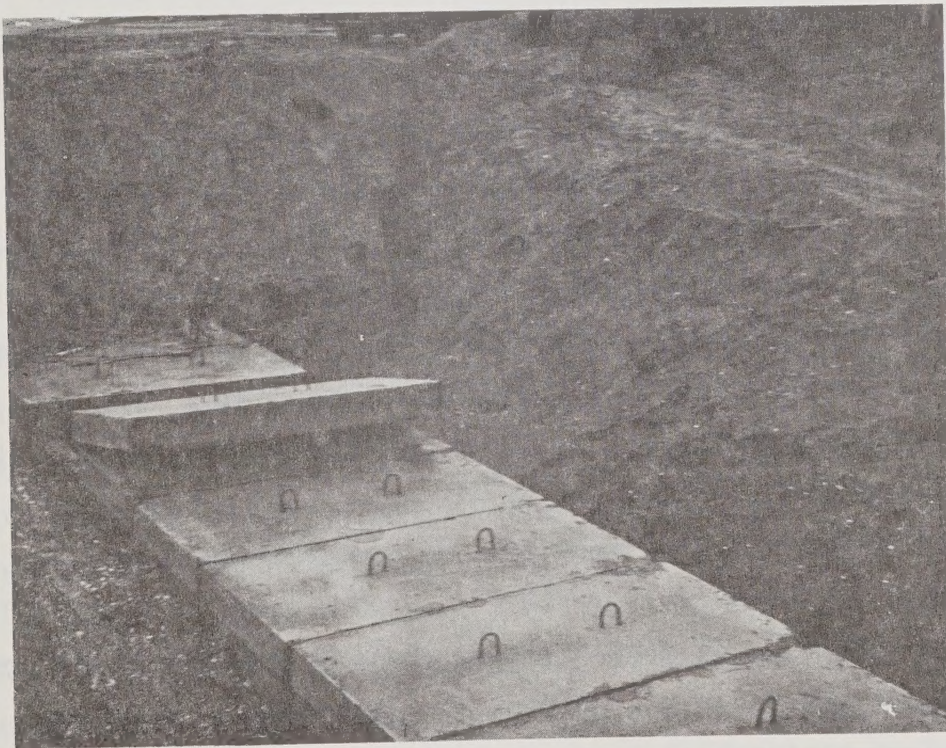


FIGURE 14. CONCRETE UTILIDOR WITH REMOVABLE TOP SECTIONS

Problems with frazil-ice choking intakes, subsequent frozen water lines, high mineral content water, corrosion and excessive water usage to prevent some systems from freezing were common [33, 34].

Although sewers were basically provided with enough heat to keep them from freezing (the intrinsic heat of the wastes passing through them) long sewer lines ran out of heat and froze, particularly those serving small installations. Vertical alignment of the sewers was difficult to maintain in places where the sewers passed through permafrost and heat from the sewer damaged structural stability of the immediate sewer environment.

Utilidors carrying steam lines became so hot it was difficult to have other than hot water at most taps. Those underground utilidors constructed of wood readily filled with water and were difficult to maintain. Such conditions also constituted a threat to safety of the water system. Water lines bathed in a mixture of groundwater, sewage and miscellaneous drainage from the utilidor itself presented an ever potential threat to the water user.

The threat of World War II also triggered other mammoth construction efforts in Alaska. Each of these efforts afforded further opportunity to construct water supply and waste disposal facilities in the North. Construction of the Alcan (Alaska Highway), Canol project including the petroleum products pipeline to Fairbanks with an additional line running to Haines from Haines Junction, small far-flung military posts along the Arctic Coast and the Aleutian Islands and the attendant facilities to support them gave new emphasis to construction concepts, techniques and operations under low temperature conditions.

The St. Paul District of the Corps of Engineers, U.S. Army, initiated investigations to provide more background information on cold weather construction and operation problems. The start was late and literature searches and resulting reports only began to appear concurrently with finished projects in the permafrost area. However, this work and interest gave rise to following efforts which resulted in establishment of the Frost Effects Laboratory in Boston, the Corps of Engineers

Permafrost Research site near Fairbanks, the Snow, Ice, and Permafrost Research Establishment at Wilmette, Illinois and later a consolidated effort through the Cold Regions Research and Engineering Laboratory at Hanover, New Hampshire. It is interesting to note that aside from information reported in the initial literature search, research need for water supply and waste disposal service information was not given visible priority in that agency until about 1963, when they participated in sponsorship of the first International Permafrost Conference held at Purdue University in Lafayette, Indiana [23]. Many of the research needs of Alaska were delineated well at the organizational meeting of the Alaska Science Conference held in Washington, D.C. in 1949 [12]. Most water supply and waste disposal concepts and developments grew through trial, error and experience with actual facilities provided for day-to-day service until late 1949. Through concerns of the Alaska Territorial Department of Health, certain interested persons in the U.S. Public Health Service and Congress, investigations were started on waste disposal systems by a new Arctic Health Research Center. This work was conducted in a temporary wood frame structure on the Campus of the University of Alaska at Fairbanks in the fall of 1949. The temporary station was closed and reopened in Anchorage in 1950 where investigations [35] on water distribution problems started in 1951 and 1952, returned to Fairbanks in 1966 and continued for several years with gradually decreasing effort until the center was closed in 1973.

A federally sponsored Alaska Public Works Program was instituted in the Territory in late 1949. This 70 million dollar program [36]. first envisioned by then Governor Ernest Gruening, C. Earl Albrecht, who was serving as Commissioner of Health, and other Territorial cabinet members, was successfully presented to the U.S. Congress by Delegate to Congress, E.L. "Bob" Bartlett. Several public facilities were built throughout Alaska under this program, including new facilities and improvements to existing facilities. The communities of Ketchikan, Petersburg, Wrangell, Hoonah, Sitka, Juneau, Haines, Skagway, Yakutat, Valdez, Cordova, Kenai, Moose Pass, Homer, Anchorage, Palmer, Dillingham,

Kodiak, Nenana, Wasilla, Nome, College, Fairbanks, and Big Delta were all beneficiaries in one way or another from the water supply and waste disposal portions of this activity. Although there were many successes in this effort there were some failures [37]. No success of the Alaska Public Works Program was any more significant though than the new community water system built in cooperation with the city of Fairbanks [38]. This was the first full scale community system in Alaska (the system was built in 1952, although later construction occurred) and perhaps in the north, designed and planned from the beginning to utilize the single main recirculating type (Figures 15, 16, 17) distribution system [15]. Prior to this time, recirculation in smaller systems at government installations and mining camps had been through use of a dual main recirculating system (Figures 18, 19). Even this type of system was rare; most of the systems in which heat was applied to the distribution lines (Figures 20, 21, 22, 23, 24) were enclosed within a utilidor or used a steam tracing system. The feasibility of shallow bury on water mains, recirculation by means of planned service loops, a modified thermal tap type service connection [15] for house services (Pitorifice) [38], gravel packed wells, use of waste heat from the municipal power plant, fire protection by use of fire wells rather than elevated storage, and cold region removal of iron from the water supply were all successfully demonstrated by this system.

The Fairbanks system also demonstrated some of the problems associated with maintaining a chemically stable water in a low temperature area water distribution system. Changes in water temperature and chemical stability were successfully controlled to prevent corrosion or deposition of excess materials in the distribution lines.

The Alaska Public Works Program stimulated a new interest and dependence upon groundwater as a source of water supply. Through some of the facilities built under the program, particularly at Anchorage, new focus was gained on the problems of using cold water in a system [21, 39]. The advantages of using warmer groundwater were definitely demonstrated. In Skagway, parts of the distribution system were destroyed by use of near freezing water in the system. Revisions to the system provided for

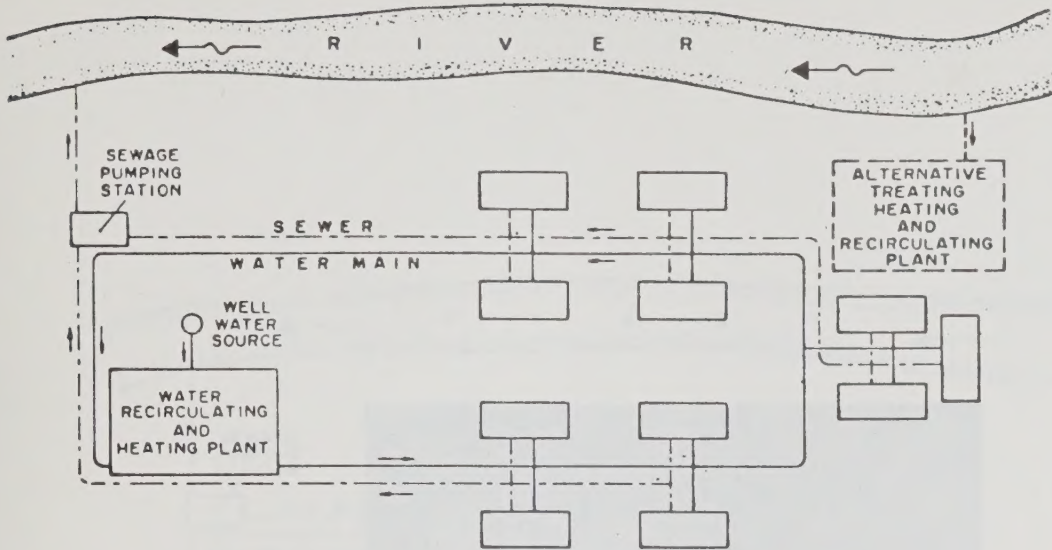


FIGURE 15. SINGLE-MAIN RECIRCULATING DISTRIBUTION SYSTEM

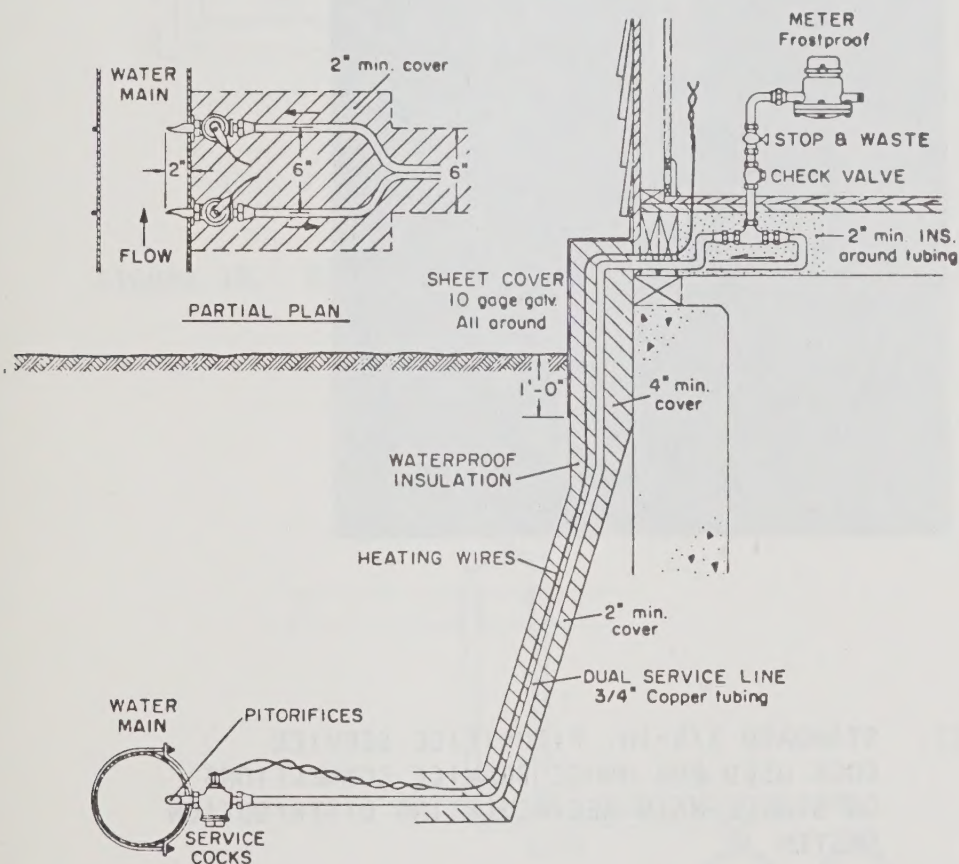


FIGURE 16. RECIRCULATING WATER SYSTEM WITH PITORIFICES AND SERVICE CONNECTIONS

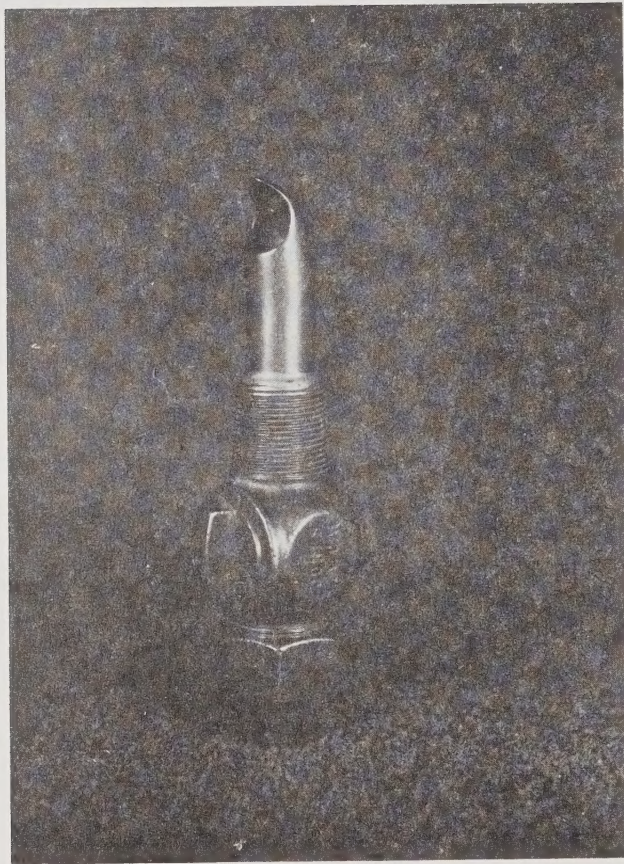


FIGURE 17. STANDARD 3/4-IN. PITORIFICE SERVICE COCK USED FOR HOUSE SERVICE CONNECTIONS ON SINGLE-MAIN RECIRCULATING DISTRIBUTION SYSTEM

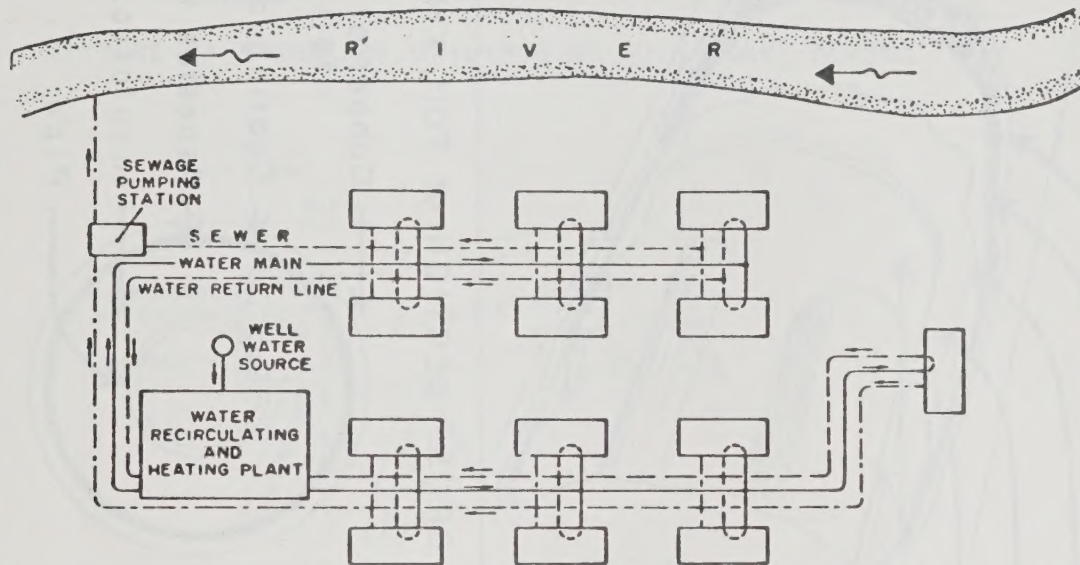


FIGURE 18. DUAL MAIN RECIRCULATING DISTRIBUTION SYSTEM

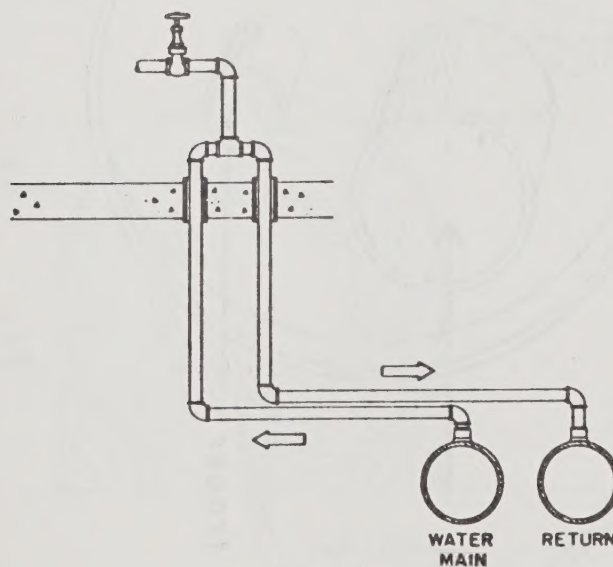


FIGURE 19. DUAL MAIN SERVICE CONNECTION

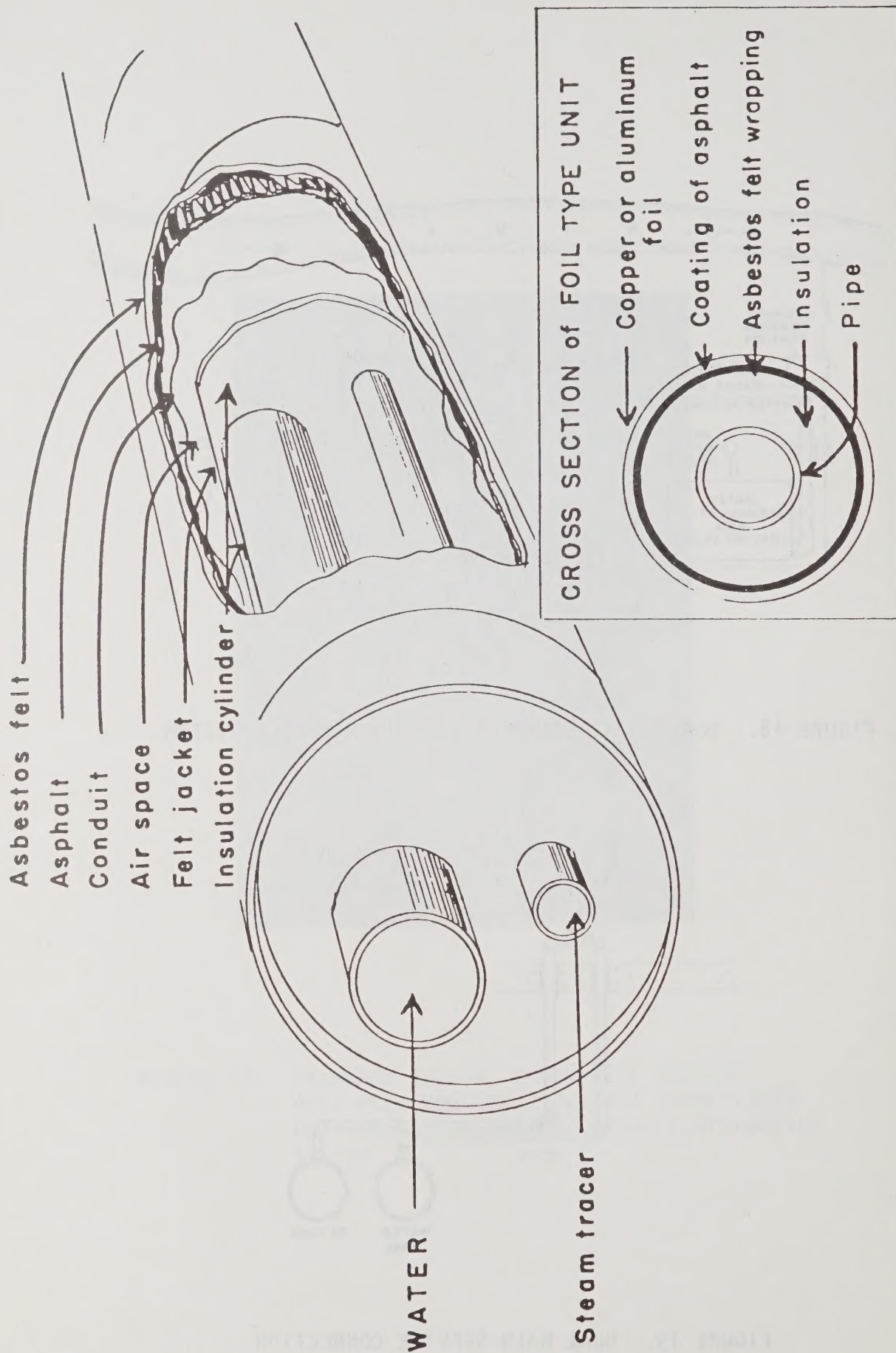


FIGURE 20. COMMERCIAL TYPE UTILIDOR (ONE OF SEVERAL DIFFERENT PREFABRICATED UNITS AVAILABLE).

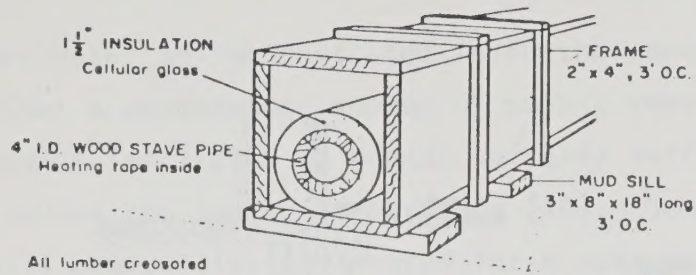


FIGURE 21. SURFACE UTILIDOR AT QUINHAGAK, ALASKA

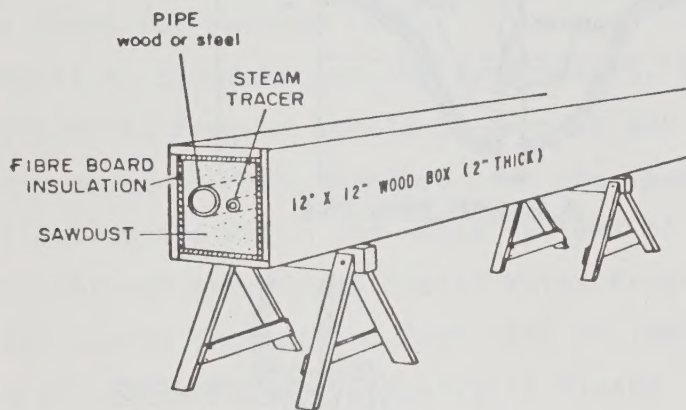


FIGURE 22. ABOVEGROUND WOOD UTILIDOR

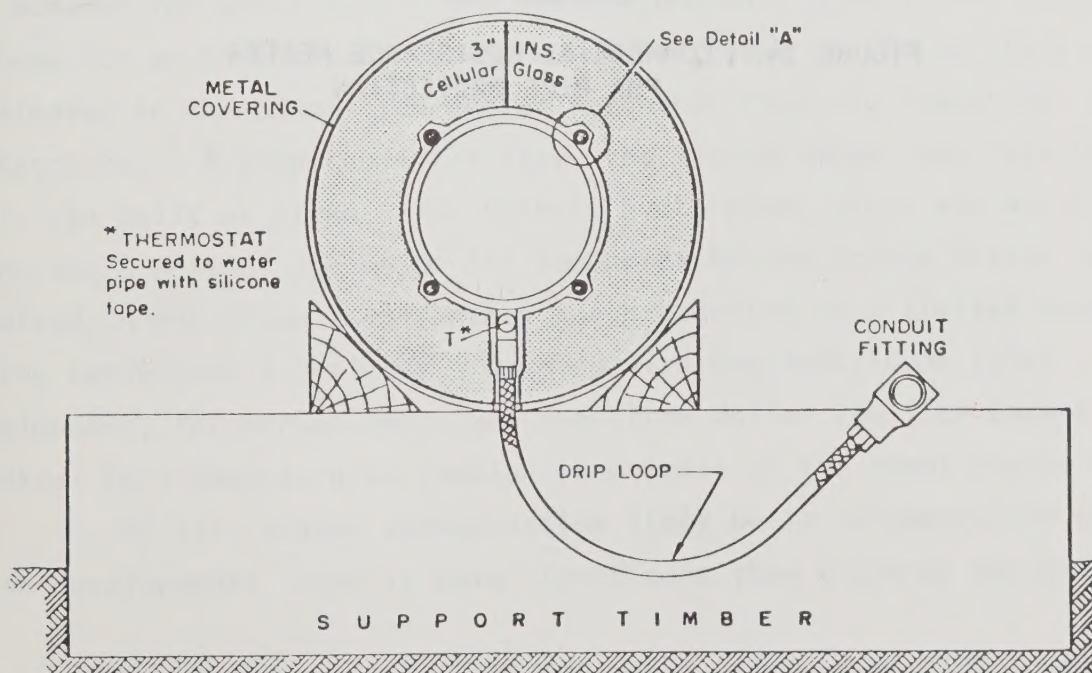
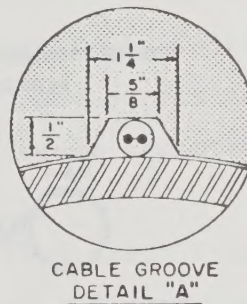
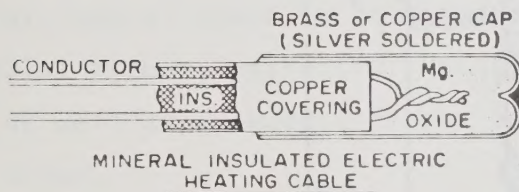


FIGURE 23. M.I. CABLE RESISTANCE HEATING

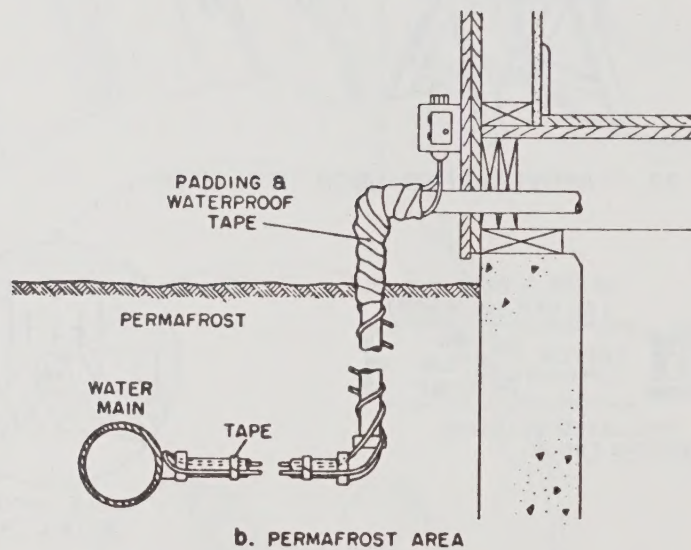
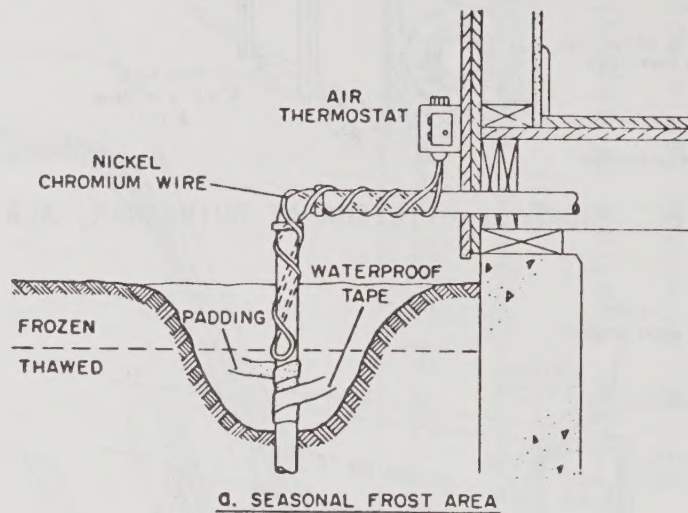


FIGURE 24. COMMERCIAL RESISTANCE HEATER FOR PIPE PROTECTION

use of warmer water and demonstrated in further developments at a later date that a groundwater source of supply should be used [22]. Storage and transmission facilities at Hoonah suffered serious damage from use of a water source too low in temperature [22]. Some of the facilities built in small communities unprepared for proper operation and maintenance failed; in such instances, it was well demonstrated that communication systems must be properly fitted to the abilities for maintenance as well as the needs for service [22].

Hurff A. Saunders and the late John D. Argetsinger of the Alaska Public Works Program should be singled out for commendation for the visionary concerns they injected into the vast program of building and rehabilitating the water and waste systems of the principal communities of the state through the Alaska Public Works Program.

The twenty year period from 1945 to 1965 reflected results from a redoubled effort to develop industry in Alaska. Beginning with establishment of the Alaska Development Board by the 1945 Alaska Territorial legislature, Territorial government and municipal governments in cooperation with several federal agencies promoted expanded harvest of Alaska resources. Potential timber, petroleum, water, fisheries, and agricultural development as well as renewed interest in mining were all promoted with considerable vigor.

Several significant industries resulted; each brought with it new demands for water supply and waste disposal. Almost four decades of hope for an Alaska pulp industry, and at least one false start, culminated in the 50 million dollar Ketchikan Pulp and Timber Co. mill at Ketchikan. A comparable facility, the Alaska Lumber and Pulp Co. mill, was built at Sitka. The Eklutna hydro-power plant was built near Anchorage. Most of the major oil companies of the United States became involved in petroleum development, and processing to a limited degree, in the Kenai-Cook Inlet area. Coupled with the Kenai-Cook Inlet development, refineries and a multi-million dollar (Collier Carbon and Chemical Co.) ammonia-urea complex were built in the Kenai region.

Of all related communication lines built in connection with these developments, none is more significant than those at Ketchikan.

The artificial impoundment (Lake Connell) and three mile long 48 inch diameter transmission line as well, as the 40 million gallon per day capacity rapid sand filter plant (with stainless steel pipe in the pipe galleries) all designed and built to serve the Ketchikan pulp mill, brought a new dimension to water works facilities in Alaska. Closely followed by the comparable plant built to serve the Sitka pulp mill, these investments almost equalled the total amount of money spent on water works in the state up to that time.

Considerable study preceeded the Ketchikan developments to determine cold region implications. The completed facilities have adequately met cold region water supply needs and provided valuable background information on the methodology for transmission and treatment of cold region water.

The 50 million dollar program to rehabilitate the Alaska Railroad during the late 1940's and early 1950's also brought about some water and waste system improvements which are noteworthy. Storage of water (Figure 25) for railroad use was originally a significant part of providing water supply. Cold region (Table 1) experiences of the Alaska Railroad constituted the greatest part of Alaskan experience in distribution system storage facilities. Aside from elevated storage for water at Anchorage, at the University of Alaska in Fairbanks, communication site storage (Figure 26) and distribution system storage at ground level on a mountainside as was practiced at several coastal communities, little attempt was made to provide distribution system storage on most Alaska systems. New railroad storage facilities built in Fairbanks and in Anchorage provided specific experience to utilize in dealing with the problems of elevated storage of water under extreme low temperature conditions.

A 500 million dollar effort to establish a Distant Early Warning System across the Arctic during the mid 1950's was also instrumental in providing background information on the problems of communication lines under cold region conditions [40]. These facilities were the first facilities to incorporate a large encapsulation technique as a solution to meeting cold weather problems. As much as possible all water supply and waste disposal operations for these facilities were

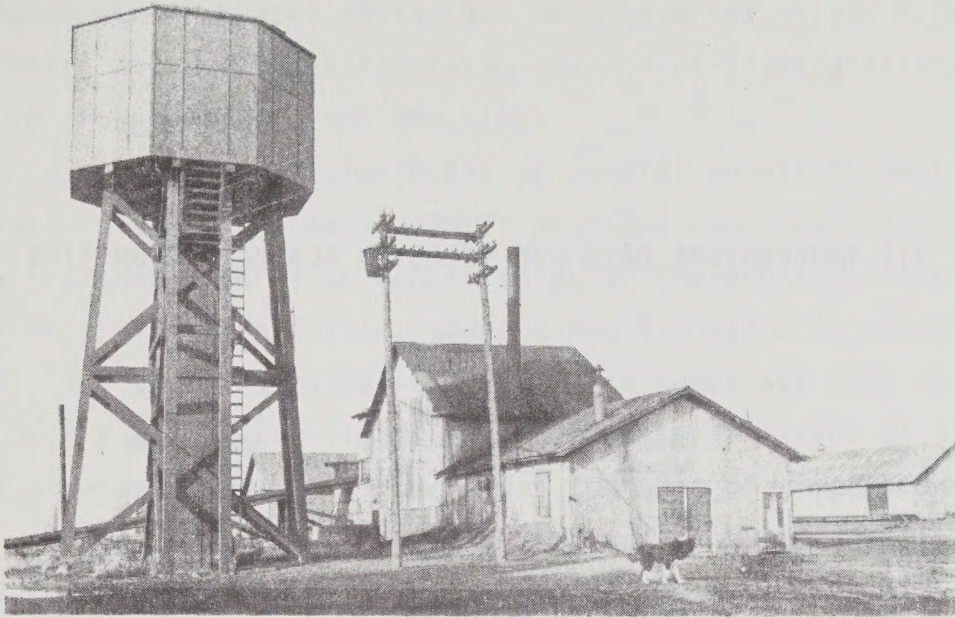


FIGURE 25. IN YEARS past, the water storage tank serving the Alaska Railroad at Nenana was enclosed and heated with steam from an adjacent pump plant to prevent freezing.

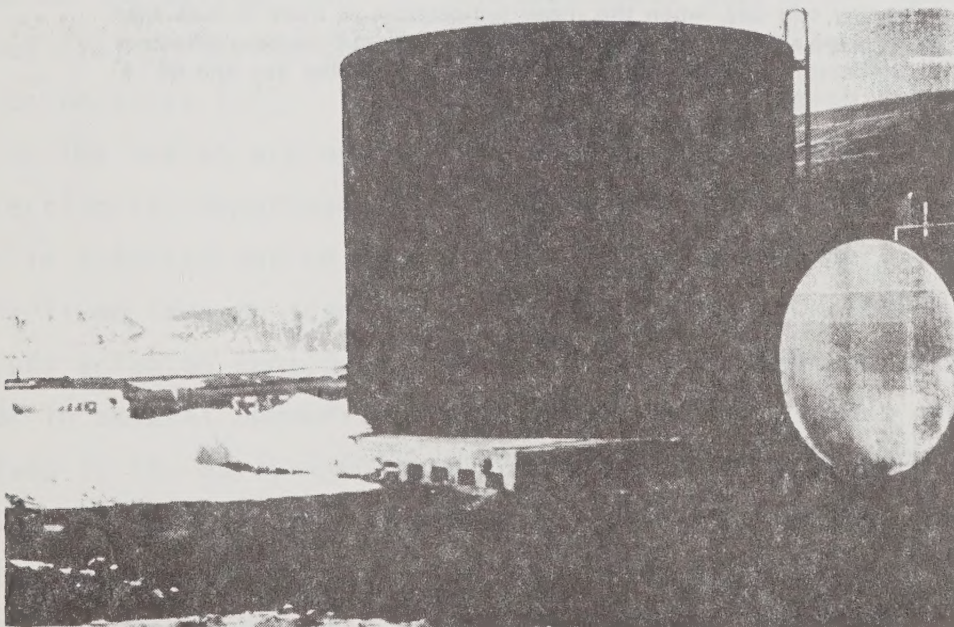


FIGURE 26. CONCRETE base under water storage tank in far north is ventilated to maintain frozen earth beneath it. Thawing of permafrost under pressure can endanger stability of structure and must be considered in polar region design.

TABLE 1. AIR TEMPERATURE DATA FOR SELECTED ALASKA COMMUNITIES

Community	Mean Annual Temp. °F.	No. Days Max. Temp. 32° F. or Less	Approximate Annual Degree Days*
Anchorage	34.7	125	11,000
Barrow	9.9	280	20,000
Bethel	29.9	140	13,000
Cordova	40.6	60	10,000
Dillingham	34.3	...	
Fairbanks	26.0	160	14,000
Ft. Yukon	19.7	...	
Galena	25.0	180	14,000
Gambell	23.4	205	15,000
Juneau	42.1	55	8,000
Kotzebue	20.7	205	16,000
McGrath	25.4	165	15,000
Nome	25.7	185	15,000
Northway	23.0	165	16,000
Umiat	9.8	240	20,000

* For any one day, when the mean temperature is more or less than 65° F. there exists as many degree-days as there are F. degrees difference in temperature between the mean temperature for the day and 65° F.

encapsulated within heated living and working areas of the site. The related White Alice project involving many small sites utilized concepts similar to those used for the DEW Line.

Air Force facilities built at several points to meet the needs of the latter 1950's and early 1960's provided many small systems which were second generation counterparts of the encapsulation techniques used earlier. These facilities added a new dimension in water storage practice. For the first time in Alaska an attempt was made as a part of this effort to provide freshwater storage capabilities at the site to meet the greatest part of station needs for most of the year.

After continual pleading by the Gruening administration and the Alaska Territorial Department of Health during the later 1940's and early 1950's, the federal congress and the federal Bureau of Indian Affairs exhibited increased interest in the health of native Alaskans. Responsibility for native health services was later transferred from the federal Bureau of Indian Affairs, within the U.S. Department of Interior, to the U.S. Public Health Service [22].

The Territorial Department of Health specifically focused attention on the serious lack of adequate water supply and waste disposal facilities [10] in native communities and the lack of other essential sanitation services [14]. In 1954 the U.S. Public Health Service, serving as the health arm of the BIA, entered into a contract with the Alaska Territorial Department of Health to provide Sanitation Aide services in selected native communities. Although BIA participation was short-lived (due to transfer of the health function to PHS) the contractual relation continued with the PHS. Limited improvements were made in several communities under this contract. This arrangement was shelved in the early 1960's to provide funds for the U.S. Public Health Service to enter into a direct facility construction program for native communities.

In cooperation with local groups, other agencies and programs and on its own, the U.S. Public Health Service water supply and waste disposal facilities construction program has been responsible for facilities in many communities. Tempo of this construction program was increased through receipt of funds provided in connection with the

federally financed effort to re-house native village people. A multi-million dollar program for planning and construction of water and waste systems was the result. Some projects are not yet completed; projects have ranged from simplest improvements to complex systems [41]. Although the effort is still in progress, by 1973 facilities had been built, were under construction, planned or improvements made in existing facilities at the following 102 communities:

Akhiok	Hoonah	Napakiak
Akiachak	Hooper Bay	Napaskiak
Allakaket	Hughes	New Stuyahok
Ambler	Huslia	Nikolai
Angoon	Hydaburg	Noatak
Anaktuvuk	Kake	Nome
Arctic Village	Kalskag	Nondalton
Barrow	Karluk	Noorvik
Bethel	Kiana	Northway
Buckland	King Cove	Nulato
Chauthoaluk	Kipnuk	Ohgsenakale
Chefornak	Kivalina	Old Harbor
Chevak	Klawock	Oscarville
Chistochina	Klukwan	Ouzinkie
Copper Center	Kohanok Bay	Pedro Bay
Crooked Creek	Koktovik	Pilot Station
Deering	Koliganak	Pitkas Point
Dillingham	Kotlik	Port Graham
Dot Lake	Kotzebue	Port Lions
Elim	Koyuk	Russian Mission
English Bay	Kwethluk	St. Marys
Fortuna Ledge	Larsen Bay	St. Michael
Galena	Lower Kalskag	Sand Point
Gambell	Manokotak	Saxman
Goodnews Bay	Mekoryuk	Savoonga
Grayling	Metlakatla	Scammon Bay
Gulkana	Minto	Sleetmut
Holy Cross	Mt. Village	Shaktoolik

Shishmaref	Teller	Venetie
Shungank	Tetlin	Wainwright
Stebbins	Togiak	Wales
Tanacross	Tuluksak	White Mountain
Tanana	Tuntatuliak	Yakutat
Tatitlek	Unalakleet	Tyonek

USPHAS planning and construction employed concepts previously utilized for communication lines with exception of improvements to the technology in many instances. Transport by hand-carriage methods was improved by providing better in-home facilities and improved water collection and disposal points. Utilidor, recirculating systems and conventional systems were utilized for communication lines in many places. This program made the first extensive use of plastic pipe and first utilized a vacuum waste disposal concept (Figure 27) for transport of wastes. Plastic pipe had been used in a limited way in connection with

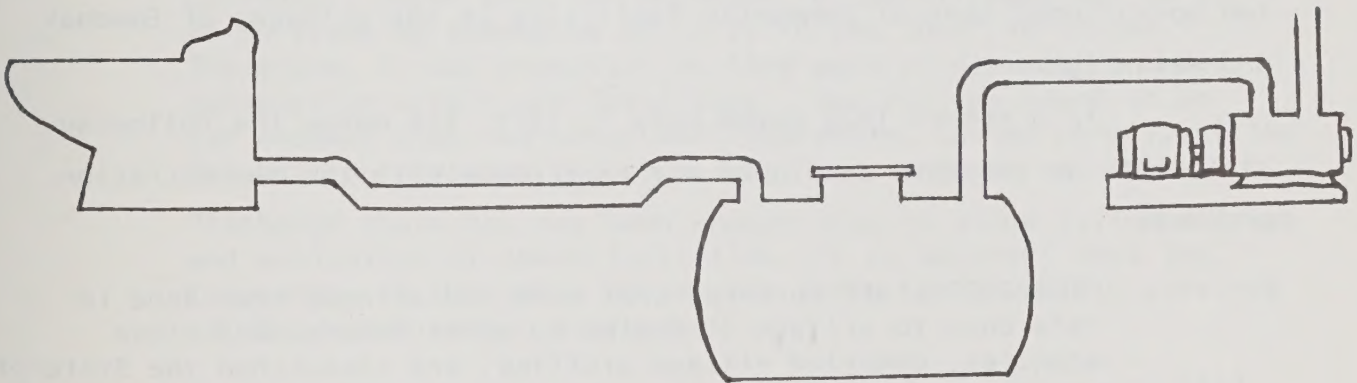


FIGURE 27. THE BROAD PRINCIPLES OF THE VACUUM WASTE COLLECTION AND TRANSPORT SYSTEM.

The vacuum system is based on a pump which maintains a constant suction in the system. When the first knob on the toilet is pushed, a valve is opened giving connection to the sewage pipe and the suction then empties the bowl.

development of wells as a source of water under the original Sanitation Aide effort, in which central water sources were developed for five

villages and the concept of water storage barrels and waste disposal pits were used in some villages. Almost concurrent development of the Alaska Village Electric Cooperative program, with provision of community electric power generating and transmission facilities in some 30 plus native villages, facilitated PHS provision of electrically operated communication lines. The USPHS program stimulated dependence upon heat sources, electric motors, control equipment, central facilities and wide use of insulation in native village water supply and waste disposal systems.

Pursuant to "Federal Water Pollution Control Act Amendments of 1972", Section 113, "Alaska Village Demonstration Projects", P.L. 92-500 (86 STAT816), "...efforts were initiated to demonstrate methods for providing central community facilities for safe water and elimination or control of pollution in those native villages of Alaska without such facilities" [42].

These efforts were undertaken by the Office of Research and Development, U.S. Environmental Protection Agency at the Alaska Water Laboratory, on the campus of the University of Alaska at Fairbanks, Alaska. The Alaska Village Demonstration Projects program resulted in two operational central community facilities in the villages of Emmonak and Wainwright.

In a report [42] dated July 1, 1973, EPA makes the following statements on concepts developed and experience with the demonstration projects:

"The AVDP staff surveyed that work had already been done in reference to village utilities by other federal and state agencies, compiled village profiles, and researched the State-of-the-Art in cold regions water treatment and waste disposal. It was established that Federal and State environmental and health standards would be met. General design concepts and processes to meet these standards were then selected.

"The application of conventional collection, distribution and treatment technology would have required investments of enormous capital in villages whose future is uncertain. Arctic and subarctic experience has shown that conventional systems which provide piped water to homes and rely upon water carried sewage are not only expensive to construct, but are also highly susceptible to failure. Seldom do such utility networks reach all homes of the village.

"The conceptual design explored previously untried approaches to meeting environmental health needs of small Alaskan communities.

"As an alternative to the conventional design, a central community facility was considered where people would perform some of the functions which are normally done at home. By having residents do their laundering and bathing at a central location and through the use of low-or-no-water-use toilets at home, total volumes of water required by a community can be drastically reduced. The amount of water needed in the home would be small enough to be individually carried or distributed by vehicles. Washing machines, dryers, bathtubs, or showers would not need to be duplicated from home to home where they would compete for precious space.

"Incineration was selected as one of the processes of the system with full knowledge that it is generally considered an extravagant use of energy. Alternatives to incineration were water carried sewage systems and sewage lagoons or another biological treatment system. However, these systems also lead to large scale sludge disposal problems. Even if sludge from the wastewater was easily disposed of, the problem of household refuse disposal would remain.

"By concentrating all utility functions at one location, incineration could economically be incorporated. Through application of heat exchangers, the incinerator could serve as main source of heat for the entire complex. Thus, energy which normally goes to waste would be conserved.

"Conservation of water was also an important objective. Currently, water used for drinking in the villages may be 30 to 50 times as expensive as it is in the lower 48 states. Therefore, it was essential to find ways of minimizing water consumption within the facilities. Hot air was found to be far cheaper than hot water and, therefore, saunas were specified for bathing purposes."

"Although there has not been enough time to allow full operation and evaluation of these facilities, it is apparent that the technology is available to provide these basic utility services to the demonstration villages."

The following is quoted from a letter of transmittal of the report [42] to the federal Congress:

"The Environmental Protection Agency is committed to actively pursue the Alaska Village Demonstration Projects Program. The preliminary results are encouraging. Public acceptance has been greater than anticipated. The demonstration projects have shown that the technology is available to provide the basic utility services to the villages of Emmonak and Wainwright. Economic considerations concerning construction costs and annual operation and maintenance expenditures must be investigated further.

"Continued research and development will provide a sound technical and social-cultural data base upon which an environmentally acceptable statewide program can be developed.

It is anticipated that additional projects utilizing technology developed in our program will be implemented by other Federal/State/native village agencies."

The 1970 Alaska State Legislature provided authority for state construction of village water supply and other sanitary facilities [22]. The electorate approved an initial three million dollar bond issue to implement the provisions of this act, but no provision was made for funding to administer the act until 1973. Later funding for the program provided funds for both administration of the act and additional projects. Although the act was initially to be administered by the Commissioner of Health and Welfare, the responsibilities had been transferred to the newly created Department of Environmental Conservation by the time it was possible to secure funding for administration. In view of the wide charge given in the act, the relatively small amount of funding eventually provided and the lack of any emergent clear concept for meeting village needs within the constraints of local economy, considerable delay occurred in initiating the program.

As the Village Safe Water Program has evolved, efforts have been directed in much the same way as effort in the EPA Demonstration Program. Concepts have been similar in provision of facilities and experience with dependability and effectiveness also parallel those experiences in the EPA effort. The VSW program has provided for facilities for the benefit of the following communities:

Northway	Pitkas Point
Chevak	Koyukuk
Nulato	Beaver
Selawik	Kongiganak
Alakanuk	

Discovery of oil on Alaska's North Slope in commercially significant quantities initiated a new era during the later 1960's in water supply and waste disposal facility construction [43]. The largest single, privately financed construction project in the history of the United States, and perhaps the world, brought about a serious need for modern services in construction camps and permanent bases. Systems which would serve a few to several hundred persons were needed. Some installations of a permanent nature were required and some facilities

were needed for short time occupancy of a site. These facilities were needed in areas which experience the harshest cold climate conditions found in Alaska.

Concepts for communication and central facilities were catapulted into the space age (Figure 28). Package plants became common and limited water reuse, minimum flow facilities, communication lines by means of aircraft and similar practices appeared. This experience provided and is providing a rigorous test of "space-age systems" with their complex technology and facilities.

If only the usual ten to twenty percent of project cost were devoted to water and waste facilities included as a part of this mammoth project, it would represent a minimum expenditure of almost three quarters of a billion dollars for water supply and waste disposal facilities.

The full story on oil-related communication lines is as yet untold. Preliminary comment would indicate the following:

1. Any type of system or process can be built, installed or operated in the North given enough money, energy and manpower.
2. These systems may not be available to persons and groups of less means.
3. Operation and maintenance is a plaguing and continual problem, even in a situation where private industry has clearly defined responsibilities for operation and maintenance.

Of the approximately 2,000 formerly or currently viable geographic points in Alaska for which community census data have been compiled, an estimated 400 could be considered eligible or potentially eligible for financial assistance in developing community water supply and waste disposal facilities. All past public programs for construction of water supply and waste disposal facilities have resulted in approximately 500 projects benefiting approximately 25% of the, conservatively estimated, potential number of places to be served. Admittedly, the communities presently served by facilities are rarely served adequately. Many places are not yet served with facilities, adequate or inadequate. Many of

the estimated 500 past projects in Alaska were repeat projects (in some places facilities have been rebuilt as many as five times) for reconstruction of facilities previously built under other public assistance programs. Through public agencies and programs (federal, state, and local) such as WPA, FWA, ARDB, AHA, BIA, APW, CAA, Weather Bureau, Department of Defense, ATDH Sanitation Aide, PHS, HUD, SBA, Farmers Home Administration, FHA, ADE, AVDP, VSW, and individual effort of local groups and communities, many millions of dollars have been spent in meeting the water supply and waste disposal needs of Alaska communities. Although many forces played a part in garnering this tremendous effort over the last 8 to 10 decades, perhaps three underlying forces have had the greatest influence. These forces might be termed: (1) the urge to harvest Alaska resources; (2) the urge to maintain a temperate climate life-style in the Arctic and sub-arctic; and, (3) a growing awareness of the needs of native Alaskans. None of the motivating influences appears closely related to development of fully efficient and effective communication lines.

Extension of rural electrification program benefits to rural Alaska did not occur until almost thirty years after initiation of this depression-triggered program in the contiguous states. However, upon introduction of the program in Alaska and provision of electric power in some 30 rural areas, drastic changes began to occur in water and waste system concepts. Power-driven and heated facilities began to replace legendary hand-carriage systems. The way was opened to provide more complex systems with need for trained operation and maintenance support on a much broader scale than ever before.

It is interesting to note that although the previously mentioned developments began many years ago and the tempo in providing such facilities has been ever increasing, many rural areas do not yet have a local government which provides for the operation and maintenance of such facilities. The state and federal governments have been reluctant to assume complete responsibility for operation and maintenance of systems. Severe problems of maintenance and operation have been the result. System dependability has left something to be desired.

CONCLUSIONS

Legendary communication lines still exist in parts of Alaska and will probably continue until it is possible to provide acceptable, simple, facilities within the operating capability and purchase price of those served. Experience has shown that the legendary systems are a hazard to health and environment and unacceptable in the lifestyle of many, but they are simple and "come naturally". Anyone can afford the system and make it work if he has the will to make it work.

Research and improvement in practice has been largely the result of the interest of a few. Investigations have been on the function and acceptability of completed projects rather than in the laboratory. No cold region environment, broad scale, continuing effort has been made to meet the unusual and basic problems presented, such as energy efficiency, cost-effectiveness, reliability under low temperature stress. Short-lived investigative efforts have been underfunded and de-emphasized. This is a sad commentary on a subject which touches the lives and pocketbooks of any and all who would make his home and find his life-style in Alaska.

Investigations of functioning facilities and guidance by hunches about what the future might hold have resulted in some well-defined conceptual patterns of practice (Table 2) in providing communication lines. These concepts are termed as follows:

1. Protective - a concept in which protection from freezing is achieved by isolation or encapsulation.
2. Insulation and heating - a concept in which it is planned to meet the heat needs to protect facilities from freezing regardless of their location.
3. Non-frost susceptible - a concept in which passive methodology is employed in meeting problems of freezing.

The successive waves of construction which provided communication lines to observe were largely triggered by specific needs, such as:

1. industrial needs of the gold mining and seafood industries as Alaska became a territory;
2. military occupational needs at the turn of the twentieth century;
3. municipal needs of the period from 1916 to 1930;

TABLE 2. WATER SUPPLY AND WASTE DISPOSAL COMMUNICATION LINE CONCEPTS CURRENTLY IN USE IN ALASKA (EXCLUSIVE OF HAND-CARRIAGE METHODS).

WATER SUPPLY

STORAGE		DISTRIBUTION	
Ground	Surface	Elevated	Piped
	Thawed Impound- ment Tank Pillow Frozen Ice mound Block ice Snow	Enclosed in building Heated tank	Utilidor Bleeder Dual main Recircu- lating Heat traced Seasonal
Pervious aquifer Rock Ice Vault Artificial reservoir or tank			

WASTE DISPOSAL

COLLECTION		TRANSPORT
Dry	Wet	
Bucket Incinerating device pit privy	Bucket Tank Flushing system Flowthrough Recirculating Vacuum	Fluid flush Gravity Pressure Vacuum Mechanical Vehicular

4. depression program employment needs of the 1930's;
5. military needs of the period from 1939 to 1946 and mid 1950's to 1970;
6. municipal and public works needs of the period from 1949; to 1959;
7. native community needs of the period from 1955 to date;
8. industrial development needs of 1950 to 1965; and,
9. oil industry needs of the period from 1968 to date.

Most of these successive waves of construction have occurred without the advance notice necessary for research and development prior to construction. Telescoped construction schedules and unyielding appropriation constraints have tended to make most jobs "rush jobs". In a period of continual rise in the gross product and general economic conditions, with the exception of brief anomalies in the thirties and other even briefer periods, private and public water and waste projects, concepts and efficiencies have not been put to severe test. With the advent of potentially greater energy constraints, protective, and insulation and heating, concepts which are not efficient may be subject to closer scrutiny.

Water supply and waste disposal communication lines are a major part of the initial cost of these utilities. Proportion of total cost varies from system to system but probably ranges from 60 to 90 percent of the cost of the system. Communication lines are also the most vulnerable part of the system. They absorb a significant part of the cost of operating a system. Normally they are subject to all the hazards of their immediate environment as well as the hazards which result from improper operation and maintenance. Storage facilities, distribution, collection and transmission lines, and service connections are particularly susceptible to freezing damage.

Serious hazards exist regardless of simplicity or complexity of service. The more complex the service facility the more likelihood for malfunction. Only in a limited way have we reached a point where fail-safe operation and dependability may be better assured by use of more complex and sophisticated methodology. All are subject to the same cold stress and potential malfunction. There may not be a ready

way out of the dilemma. I am optimistic enough to believe there is a way out. In review of our development:

1. Water supply and waste disposal communication lines provided by persons hand-carrying water and wastes served nomadic people needs but our current life-style is no longer nomadic. Such systems are a present day anachronism.
2. Group purpose for communication lines in Alaska has changed from a concept of providing a mere utility for utility function to an object for both environmental management and maintenance of life-style.
3. An air of affluence portrayed by an attitude of "anything can be done even to putting a man on the moon" is the tone of the times. Given enough money, energy and perseverance even the most complex utility network can be constructed and operated at any place anytime.
4. Enhanced emphasis upon satisfaction of individual needs has tenuously sprawled communication lines to serve widely scattered sub-divisions, small disconnected groups, and ribbon-like developments in helter-skelter fashion.
5. Harsh Alaska environment tends to magnify problems associated with even the simplest communications lines. Further sophistication of simple systems without full provision for continued operation and maintenance appears to have a cumulative negative effect on dependability and costs. Soaring energy costs coupled with shortages of energy and increasing resistance to public funding for communications lines may promise leaner days ahead.
6. There is an apparent trend developing which would approach problems of communication lines by modifying them to conform more closely to some of the earliest concepts. Carrying water and wastes by hand or power drawn vehicle has persisted in practice from earliest times but in some new facilities of a permanent nature distribution and

collection by powered vehicle is an integral part of initial planning of the system.

7. Contemporary influence has substituted dependence upon communication lines for delivery of service from a central source, as well as dependence upon a central source, for past individual self-reliance. In legendary service a person could walk with a bucket of water or wastes to the point of collection or discharge. This change to dependence upon community rather than self-reliance is contrary to social custom of legend and out of harmony with the arctic environment. This trend might be construed to represent a widening gap between societal need and responding practice.
8. Legendary experience of people in the North points to attainment of group purpose by composing a community of self-reliant persons. In this way, both the individual and the community gained the strength to subsist in what would normally be called a hostile environment. Projecting this thought into utility service delivery systems, how can the individual property to be served become more self-reliant? Given the dormancy and activity cycles of cold region environment, experiences of the past and the technology of today, is it possible to reduce dependency upon communications lines by increasing the self-reliance of the individual to be served? Each time a potential user has need for water, is it essential that when the faucet is opened, a complex and extensive network be activated to procure service from a central source? Is it essential that many miles of complex sewerage be put into service for a moment just because a person at the far end of the system flushes a toilet? Technologically, is it possible to relate communication line needs more closely to human need under constraints imposed by cold region environment?

SUMMARY

In summary, early development of water and waste disposal communication lines in Alaska displays many examples of ingenious concepts,

devices and systems. Concepts as simple as hand-carriage of water and waste and as complex as space-age technology would permit are in use. Power drawn vehicles, heated piping networks, heated and encapsulated piping networks and non-frost-susceptible transport media have been used. Pressure actuated, vacuum operated and gravity systems have been tried. Various heat sources such as cold ground water, waste heat, steam or electric tracer, and wood and fossil fuel fired boilers have been used. Facilities have been provided for short operational sorties into the North and for permanent occupancy of a site. There is a wealth of early, historic and contemporary experience to draw from.

Little research has been done on communication line concepts or their relationship to community and general life-style. Some research has been done on specific methods. This latter-mentioned research and investigation has been done largely through observation of construction and operation of fully-functioning facilities.

Our experience demonstrates the importance of thorough consideration of basic purpose and needs for communication lines. Systems which respond directly to these needs are effective. The harshest, perhaps the ultimate, measure of success for any communications system is the degree to which it meets basic needs, in contrast with frivolous or passing need, on a continuing basis.

REFERENCES

1. Lantis, Margaret, Consulting Anthropologist, Personal Communications 1954.
2. Report of the Cruise of the U.S. Revenue Cutter Bean and the Overland Expedition, Government Printing Office, Washington, 1899, 144 pp.
3. Alter, A.J., Water Supply in Cold Regions, Cold Regions Science and Engineering, Monograph III-C5A, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire 03755, 1969.
4. Alter, A.J., Sewerage and Sewage Disposal in Cold Regions, Cold Regions Science and Engineering Monograph III-C5B, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire 03755.

5. Alter, A.J., Water and Waste Systems for North Slope Alaska, Tape/ The American Plumbing Engineer, Building System Design, April 1970.
6. Oswalt, Wendall H., Alaskan Eskimos, Chandler Publishing Company, Scranton, Pennsylvania, 1967.
7. Honigman, John J., "The Kaska Indians-An Ethnographic Reconstruction", Human Relation Area Files-Reprint, Yale University Publications in Anthropology, No. 51 (reprinted from 1954 edition), 1964.
8. McKennan, Robert A., "The Chandlar Kutchin", Arctic Institute of North America, Technical Paper No. 17, September 1965.
9. Gruening, Ernest, The State of Alaska, Random House, New York 1954, 606 pp.
10. Parran, Dr. Thomas, A Survey of Health Conditions in Alaska, a special study made for the Alaska Territorial Department of Health and the U.S. Department of Interior, 1950.
11. Parran, Dr. Thomas, Miscellaneous Reports, Alaska Area Native Health Service, Office of Environmental Health, Indian Health Service, U.S. Department of Health, Education and Welfare, Anchorage, Alaska.
12. Parran, Dr. Thomas, Proceedings, Alaska Science Conference, Alaska Division, American Association for the Advancement of Science, 1949-1974
13. Bancroft, Hubert Howe, History of Alaska 1730-1885, Bancroft Company, San Francisco, 1886, 775 pp. (Reprinted Antiquarian Press Ltd., New York 1959.
14. Bancroft, Hubert Howe, Community Facility Needs in Alaska, Testimony before the United State Congress, 1949.
15. Alter, A.J., Arctic Sanitary Engineering, a thesis prepared for the degree of Professional Civil Engineer, Purdue University, Lafayette, Indiana 1948, 106 pp.
16. Alter, A.J., Community Facility Needs in Alaska, Territorial Department of Health, 1948.
17. Alter, A.J., The Sanitation Aide Program, Files of the Alaska Territorial Department of Health, 1952-1955.

18. Aitken, G.W. et al. (1962-1968) Ground Temperature Observations, Alaska. U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) Technical Reports 100-114. (Also similar U.S. Weather Bureau Data, for various Alaska stations.)
19. Bates, R.E. and Bilello, M.A., Defining the Cold Regions of the Northern Hemisphere, USA CRREL Technical Report 178, 1966.
20. Alter, A.J., 'Water Supply and Waste Disposal Concepts Applicable in Permafrost Regions', 2nd International Conference Permafrost, National Academy of Science, Washington, 1973.
21. Nyman, F., Temperature observations near water mains in Anchorage, Alaska. Personal Communication, September, 1954.
22. Nyman, F., Miscellaneous Files of the Alaska Territorial Department of Health, 1936-1959.
23. Nyman, F., First International Conference Permafrost, Purdue University, National Academy of Science, Washington, 1963.
24. Myman, F., File material pertaining to Alaska Juneau Gold Mining Construction and Operations, 1912-1944.
25. Alter, A.J., 'Water Supply Problems of the Arctic'. Alaska's Health, vol. vii, no. 3, 1949.
26. Page, W.B., 'Heat Losses from Underground Pipelines', Science in Alaska, Proceedings, Fourth Alaska Science Conference, 1958.
27. Rogers, H.C., A Survey on Available Standards of Sanitary Features on Utilidor Construction and Substitutes Therefore in Arctic Installations. National Research Council, Committee on Sanitary Engineering and Environment, December, 1948.
28. Thomas, R.F., 'Water Treatment Ladd Air Force Base', Science in Alaska, Alaska Science Conference, 1952.
29. Clark, L.K., Alter, A.J. and Blake, L.J., 'Sanitary Waste Disposal for Navy Camps in Polar Regions', Journal of the Water Pollution Control Federation, Vol. 34, no. 12, pp. 1219-1234, 1962.
30. Cronkright, A.B., 'Water Supply Problems of the Arctic', Public Works, vol. 78, no. 8, p. 18, 1947.

31. World Health Organization, Medicine and Public Health in the Arctic and Antarctic. Selected Papers from a Conference, WHO, Geneva (Public Health Paper Number 18), p. 169, 1963.
32. Sterling, C.I., "Sanitary Engineering in Alaska". Journal of the Boston Society of Civil Engineers, vol. 42, p. 345, October, 1955.
33. Alter, A.J., "Low Temperature Problems in Alaska", Journal of the American Water Works Association, vol. 47, no. 8, p. 763, 1955.
34. Alter, A.J., "Thermodynamic Considerations in the design of Alaska Water Distribution Systems". Proceedings, Fourth Alaska Science Conference, p. 36-38, 1953.
35. Alter, A.J., "The Effect of Ground Temperature Conditions Upon the Design of Alaska Water Distribution Systems". Proceedings, Sixth and Seventh Science Conferences, Alaska Division AAAS, 18 p. 1955-1956.
36. Alter, A.J., "Community Facilities for Alaska". Alaska's Health, vol. 8, no. 1, p. and 2.
37. Alter, A.J., "Water Supply in Alaska". Journal of American Water Works Association, vol. 42, no. 6, p. 519-532.
38. Westfall, H.C., Beck, R.W. and Associates, "Research and Design of a Single Main Recirculating System". Proceedings, Fourth Alaska Science Conference, Alaska Division, AAAS, p. 48-53, 1953.
39. Poye, W.B., "Design of Water Distribution Systems for Service in Arctic Regions". Water and Sewage Works, vol. 101, no. 8, p. 333-337, 1954.
40. McConnell, M.E., "Engineering for the DEW Line, V: Water and Waste Systems". Western Electric Engineering, vol. 11, no. 3, p. 534, 1958.
41. Ryan, W.L. and Lauster, K.S., "Design and Operation of a Water System for the Eskimo Village of Unalaklett, Alaska". American Water Works Association Conference at Bal Harbor, Florida, 1966.
42. Alaska Village Demonstration Projects, U.S. Environmental Protection Agency, Washington, D.C. July 1, 1973, 73 pp.

43. Alter, A.J., "Problems of Water Supplies in Severe Climatic Conditions", Proceedings, International Water Supply Association, Ninth Congress, 1972.

UTILITY DISTRIBUTION PRACTICES IN NORTHERN EUROPE

by

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BACKGROUND

This report represents information on utility distribution systems gathered on a study trip to Scandinavia and Great Britain and Iceland. The information concerns new technology and materials in cold weather related problems and solutions. The distribution systems involved are: water and sewage lines, vacuum sewage and pneumatic solid waste collection lines, heat distribution lines and electrical transmission lines.

In Sweden much information was obtained on plastic pipes for water and sewage lines and frost penetration protection. There are large district heating systems in operation and much information was found on heat distribution pipe systems and long distance heat transmission.

In Norway, where almost all electricity is produced by hydro-electric stations, information was collected on electric transmission line icing problems and self supporting aerial cables for electrical distribution.

A wealth of information was gathered in London where the water and sewage systems are among the oldest and largest in the world and where some material and methods have a long history of success and other new ones are being introduced. District heating technology is also highly developed in London, but large systems have not yet evolved. Pneumatic solid wastes collection systems are being introduced.

WATER DISTRIBUTION LINES

The use of plastic, particularly unplasticized polyvinyl chloride (UPVC) and high density polyethylene (HDPE), is more extensive in Europe than in the United States. Many of the codes have been modified in Europe to allow the use of plastic piping and it is used extensively, particularly in corrosive soils. It has found much favor in its ability

to carry the needed loads, its ease of installation, and its ability to resist corrosive conditions in the soil. During the ten year period from 1960-1970 the consumption of polyvinyl chloride in the Nordic countries has increased from about 30,000 tons in 1960 to 150,000 tons in 1970. Recommended lifetime for plastic water piping has been set at 50 years.

Two particular disadvantages have been noted with the use of plastic pipe. There are: (1) the inability to thaw the pipe with low voltage high current techniques as is possible with metal pipes; and, 2) the inability to detect leaks with the use of audio listening devices. Plastic pipes can, however, be thawed by the use of external thaw tapes, a technique commonly used in this country as well as Europe. Several advantages considered by the Scandinavians to be noteworthy, include the fact that plastic pipe has inner surfaces that are very smooth resulting in lower friction loss and thus higher flows in a given diameter than with the rougher metallic pipes. Plastic pipes are also flexible and can deform with stresses to some degree without failure, thus eliminating some breakage that might occur in rigid pipes. Plastic pipes also are light, therefore lowering the transportation cost to the site and the ease of installing the plastic pipe also reduces labor cost. In addition, the low thermal conductivity of plastic pipes means lower heat losses; therefore, the risk of freezing is somewhat less.

Some of the negative factors concerning plastic pipe include the fact that plastics react differently to stresses than do metals. Therefore, not only must the stress but also the time and temperature factors be considered. In addition, European engineers feel that plastic pipes require a more carefully controlled backfill material to assure that no heavy or sharp materials damage the pipe when the trenches are backfilled.

Solvent cementing to join polyvinyl chloride pipe is a subject of considerable controversy in Europe. The English, in particular, have completely banned the use of solvent welding because of the claimed brittleness of the solvent welded joint.

Prestressed concrete pipe is also used rather extensively. One particularly interesting application is that of ramming prestressed concrete pipes through roads without disrupting the road bed. Water lines

are laid up to the road in trenches, a hydraulic ram is then brought in which literally rams the prestressed concrete pipe through the road bed without disrupting the road. This, of course, is only possible in areas where the road bed is not gravel. However, it has proven very acceptable as a means of avoiding traffic disruption when water lines must be laid across the roadway. This technique would probably not be particularly applicable to frozen silt such as we have in most of our permafrost areas.

Some concern is emerging in Europe over the use of short lifetime materials. It is felt that, because of inflationary trends and the additional cost of materials and labor at this time, to use more lasting materials would be a good investment when compared to the replacement cost in, say, 50 years. Another technique which has found much favor in London is the use of plastic lining to rehabilitate old lines which have started to fail. The technique used here is to draw the plastic lining, whose outside diameter is slightly less than the inside diameter of the old cast iron pipe, through the length of the cast iron pipe that is to be rehabilitated. The cast iron pipe then acts as the tunnel and the exterior support but is no longer required to be water tight. The wall of the plastic liner is much smoother on the inside than the old cast iron pipe and it is found that even though its diameter is smaller, since its frictional head losses are less nearly equivalent flows can be expected through the newly lined pipe. In addition, all leaks and losses are eliminated with this technique, and the installation costs are only a fraction of those for new lines.

Utility distribution in Stockholm, which has existed for several hundred years, presents a considerably different problem. The location of many of the utilities installed in years past are unknown. In addition the compact, densely crowded conditions in the city make it very expensive and difficult to install by conventional means, that is, by trenching down the middle of the street. Swedish engineers have developed the art of rock tunneling to a very high degree, and it is considered to be considerably less expensive to tunnel a hundred feet (about 30 m) below the city in the solid rock on which Stockholm rests. Tunnels, 4 m (about 12 ft) in diameter are constructed to the area which

is to be served by the utility. Vertical risers are then installed for each block so that all utilities, heat, water, electric, and sewage can be taken to that particular block. Utilities are then distributed on the surface throughout the block. In this manner the entire utility system can be provided without once tearing up the street, disrupting traffic, or causing loss or damage to older utilities during the trenching operation.

SEWAGE COLLECTION SYSTEMS

In sewage collection systems, cast iron lines are largely being replaced by ductile iron. Ductile iron is very competitive with cast iron at this time, due to a recent code change which allows thinner wall ductile iron pipes to be used in many applications. Rigid joints are no longer allowed. All joints in sewage distribution lines must be flexible materials such as rubber O-rings and slip collars.

In England, brick is still used and preferred by many to other types of piping for very large sewage lines. The largest sewer line in London is 4.7 m (15 ft 6 in) in diameter. Brick lines are considered to have many advantages. They provide better footing for personnel working inside, and they are easy to repair and offer very good lifetime.

The Electrolux Corporation, in Stockholm, Sweden, manufactures components to be used in vacuum sewage collection systems. The vacuum sewage system has many advantages, among the most important of which is the fact that no trenching or grading of lines are needed. Since trenching comprises 80% of the total installation costs of the distribution line, elimination of this requirement is a large economic advantage. A report on the Noorvik, Alaska system which uses Electrolux components will be presented later by the Alaska Native Health Service.

At the present time Electrolux has 25,000 vacuum toilets on the market, 10,000 of these are on shipboard systems while the other 15,000 are in various vacuum systems in small communities around the world. Some of the installations in Sweden are in villages of 3,000-4,000 persons, and one large system in Germany has 1,000 houses on a single system.

In permafrost areas such as those in Alaska and northern Canada, elimination of the trenching requirement becomes a significant advantage.

SOLID WASTE COLLECTION SYSTEMS

One innovative system that was observed in operation in London was a vacuum solid waste collection system (Figure 1). This was used in a new apartment complex on the west edge of London. While this concept is not unique to Europe (there are also some proposed for the U.S.) it does represent the state-of-the-art. The system was in operation and fully functional. The system consists of a 79 cm (20 in) pneumatic tube which connects the 1500 apartment complex to the collection facility. The apartment buildings have collection bins in which residents can deposit their solid wastes. Bins are periodically opened to the vacuum line allowing the waste to be transported to the collection center where they are segregated and the combustible portions used to fire a hot water boiler. Supplementary heat is provided in three oil fired boilers. The heat generated by the boilers is used for heating the apartment complexes.

This system has several advantages. Since it is completely enclosed, all vermin and rodents are eliminated. Odors are kept to a minimum and segregation of burnables and nonburnables is largely done with the use of a cyclone separator which effectively sorts light and heavy materials. Light materials are predominantly burnable whereas the heavy materials with little additional handling are sent to a local sanitary landfill.

The personnel maintaining the operation have reported very little difficulty. Air velocities in the tubes during the collection phase are in the neighborhood of 27 m/sec (60 mph) and no problems have been encountered thusfar with plugging of the large main tube. Noise is considered somewhat of a disadvantage; however, while watching a sample cycle, we found the noise little more than would be normally encountered from a team of garbage men working through the neighborhood collecting the garbage. The overall system was most impressive. A convenient disposal chute was located within a few steps of virtually every apartment in the complex. Collection was controlled from the central facility and collection cycles are timed to be in periods when noise levels encountered during the collection are acceptable.

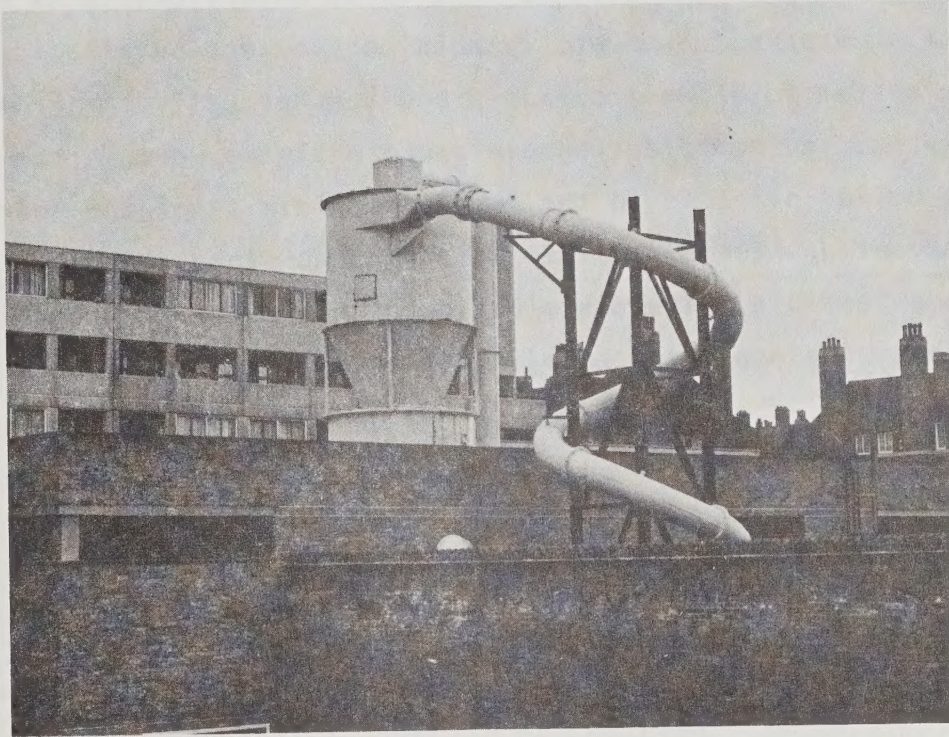


FIGURE 1. COLLECTION PIPES AND CYCLONE SEPARATOR

Interlocks prevent the doors on the individual depository chute from opening during the collection phase so that there is no possibility of unwanted material being sucked in during the collection cycle. One disadvantage is that the collection and boiler plant must necessarily be in the immediate vicinity of the apartment complex, since long distance transportation of the garbage is not feasible. The aesthetics of the large diameter pipe might also be considered objectionable as might be the boiler stacks. However, in this particular installation, we found the system to be well designed and aesthetically far from unpleasing. The stacks emitted no objectionable smoke while we were in the vicinity. Since the boiler plant is in the immediate vicinity of the apartments, this disadvantage was turned into an advantage since the district heating then became feasible. The distribution of hot water from the boiler plant to heat the apartment complex completed the cycle.

HEAT DISTRIBUTION

The Extent of District Heating

Effective heat distribution is the key to successful district heating. Hot water is the commonly used medium. It is preferred over steam because the pipe system is less costly, lower distribution temperatures can be used to reduce transmission heat losses and production costs, the flow rates can be varied to the lowest desired values, and finally, water permits efficient storage for load management.

District heating has been built up in Sweden, Finland and Denmark over the past twenty years or more and big systems are in operation today. In England, there are many small systems. In Iceland, the whole capital is served by geothermal district heating. This represents half the country's population and avoids the need to import 200,000 tons of fuel oil.

The energy savings attainable with district heating, particularly with combined generation of electricity and heat, are providing a strong incentive for an accelerated program to build heat distribution systems in Europe. The reduced air pollution and greater fire safety obtained by eliminating fuel burning in every building are an added benefit.

Table 1 summarizes basic information for comparison of district heating in Finland, Sweden and Reykjavik, capital of Iceland. The

TABLE 1. SUMMARY OF DISTRICT HEATING DATA; FINLAND, SWEDEN, ICELAND

	District heating capacity MW(TH)	Length of Distrib. lines km(miles)	Thermal energy sold TWH=10 ¹² Wh	Equivalent full load hours (load factor %)	Electricity use TWh	Share of hydro- electricity %
Finland (1971)	2055	544 (340)	5.14	2500 (28.6)	23.5	45
Sweden (1972)	6570	2250 (1406)	13.76	2100 (24)	70	78
Reykjavik	300	328 (205)	1.36	4000 (46)	0.285	>90

system utilization factors are indicative of the climate. In Reykjavik the utilization is very high, owing to the relatively even and long lasting cold weather. In Finland and Sweden, the cold weather is less severe and the heating season shorter. There is more electricity used in Sweden and Finland than district heat, much of it by industry. There is, however, much electric space heating in Norway because there is abundant electricity from hydropower. There is, therefore, no district heating and only relatively little oil heating. In Reykjavik, on the contrary, all heating is through heat distribution; electricity use represents only a fraction of the energy requirements. This means that for non-industrial purposes, most energy needs are thermal which can be met through heat distribution from heat and power plants; they produce typically about twice as much district heat as electricity.

DISTRIBUTION METHODS

The largest distribution system in Scandinavia is probably the one serving Stockholm with a 1974 capacity of 550 MW(th) for the central city and nearly as much for the western and southern districts which are interconnected. The largest main hot water transmission lines have diameters of 1000 mm (about 40 inches). They branch out into smaller mains and service lines. The design water velocities are 3 m/s (about 10 ft/sec) for large pipe diameters and lower for smaller diameters.

Table 2 lists the normal values used for design in Sweden. The table also lists the thermal transmission capacities for the various pipe sizes, based on a temperature difference of 55°C (99°F) between supply and return. This is the normal design condition.

The distribution systems are closed loop water systems with supply and return pipes side by side. Final distribution within buildings is through secondary hot water systems connected through heat exchangers. The isolation provided by the heat exchangers protects the primary and secondary systems from each other in case of a failure; the primary system also operates at higher temperatures and pressures than the secondary systems.

The supply temperature in the primary systems is 120°C at the coldest design weather conditions and the return temperature is typically 65°C . In warmer weather the supply temperature is reduced as shown in Figure 2 until it is 70°C at an ambient air temperature of about $+4^{\circ}\text{C}$.

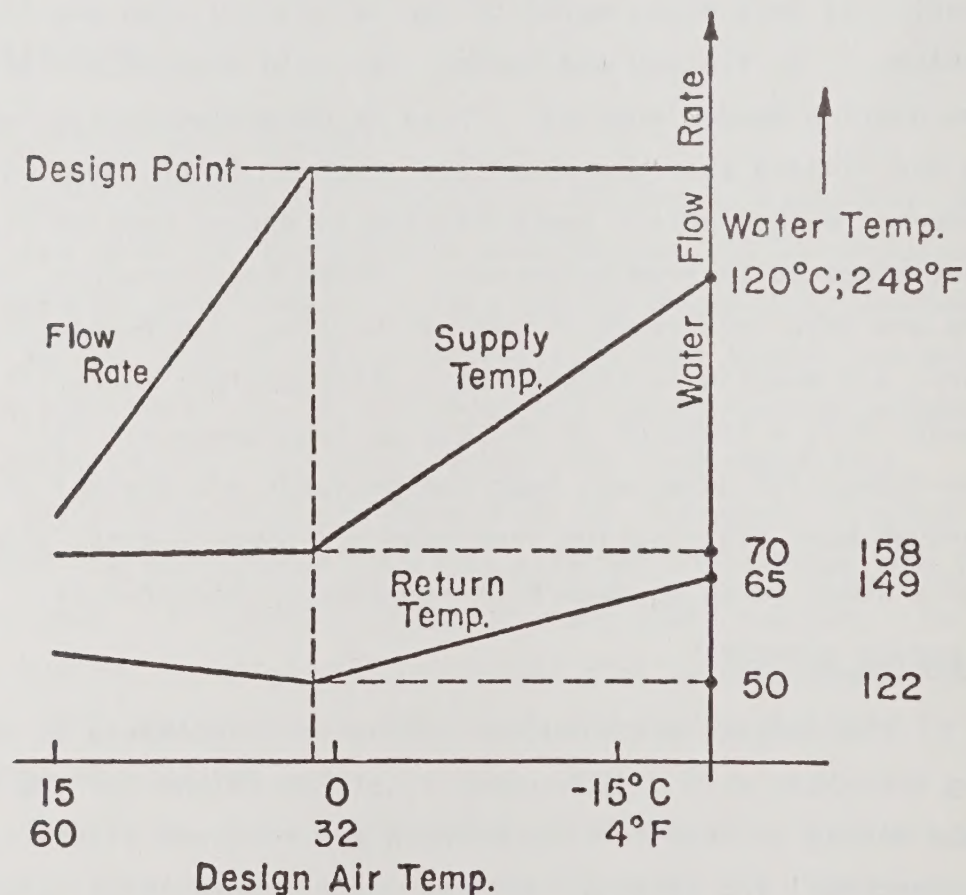


FIGURE 2. TYPICAL HEAT DISTRIBUTION WATER TEMPERATURES AND FLOW RATES. During cold weather the supply temperature is adjusted according to the air temperature while the flow rate is nearly constant at the design capacity.

TABLE 2. WATER VELOCITIES AND THERMAL CARRYING
CAPACITIES OF HOT WATER PIPE LINES

Pipe inside diameter mm	Water velocity m/s	Capacity ($\Delta T = 55^{\circ}\text{C}$) MW(th)
32	0.9	0.2
40	1.0	0.3
50	1.2	0.6
65	1.4	1.2
80	1.6	1.9
100	1.8	3.6
125	2.0	6.1
150	2.2	9.8
200	2.5	20
300	2.7	45
400	2.8	75
500	2.9	125
600	3.0	190
700	3.0	260
800	3.0	340
900	3.0	430
1000	3.0	530
1200	3.0	760
1300	3.0	890
1400	3.0	1030
1500	3.0	1180

The return temperature is then about 50°C . At still warmer ambient conditions the reduced heating load results in lower flow velocities in the system.

The secondary distribution from heat exchanger stations serving large simple buildings or groups of individual residences is with water supply temperatures of about 85°C and return temperatures of about 55°C . With lower temperatures in the primary supply system, these temperatures may drop to about 65 and 45°C , respectively.

The distribution system in Reykjavik differs significantly from the conventional practice because the geothermal hot water is used for once-thru flow only. The supply temperature is about 82°C and after use for heating, the water is discharged into the sewage system at about 45°C . Some efforts have been started to use the 45°C water for sidewalk and street heating for ice and snow control. The geothermal hot water is clear water of such quality that it can be used for cooking and general consumption.

Only in recent years has part of the distribution system been built with supply and return lines because the new wells are delivering water near 120°C . This hot water is blended with 45°C return water to provide the normal supply temperature of 82°C .

Heat losses in heat transmission and distribution with hot water are typically about 6%. Such losses must be considered to be very reasonable and show the efficiency with which heat can be transmitted. The pumping power required for the circulation of the hot water is near 1%.

The storage of hot water in large insulated tanks is an important part of heat transmission. Storage is used in the Reykjavik system to meet peak load demands while the wells and main transmission lines provide a more or less constant flow. Storage also provides insurance against supply interruptions, scheduled or unscheduled. When heat is supplied through combined generation at heat and power plants, as in the conventional European systems, storage facilities are used for load management. Hot water goes into storage during periods of high electric generating needs and is drawn from storage when electric generation is low. Typical storage capacities are about three to six hours of heat transmission capacity.

Pipe Systems for Transmission and Distribution

The methods used to install heat distribution pipe lines in Northern Europe show some special developments that are noteworthy. They are refinements of conventional methods providing more economical installation of the many miles of small service lines needed to connect all the customers to the heat mains. Another area is the evolving development of pipe systems for long distance transmission of large amounts of heat.

The different types of hot water pipe systems used in Northern Europe are as follows:

Pipe Lines in Tunnels

For large main transmission lines in Stockholm, tunnels have been cut through rock under the city where they do not interfere with other utility lines and subway systems. They are feasible for pipe diameters of 600 to 1000 mm (about 24 to 40 in) and even larger. They have transmission capacities of several hundred Megawatts (thermal). Figure 3 shows two pairs of hot water lines in a rock tunnel in Stockholm.

Utilidors

Underground utilidors are used to a small extent for pipe sizes up to 800 mm (about 32 in). They are an alternative to tunnels where rock formations are not given. Large prefabricated concrete or steel pipes are used for construction of the utilidors. Figure 4 shows the pressing of concrete pipes under a highway as an example of construction without opening a trench. Figure 5 shows the inside of the concrete pipe utilidor with two 800 mm pipes.

Concrete Culverts

Concrete culverts are commonly used as everywhere else, for pipe sizes of 150 to 800 mm (about 6 to 32 in). Figure 6 shows a cast-in-place culvert for a large single-pipe line under construction in Iceland. Prefabricated concrete culvert sections are also available. They accelerate the construction process.

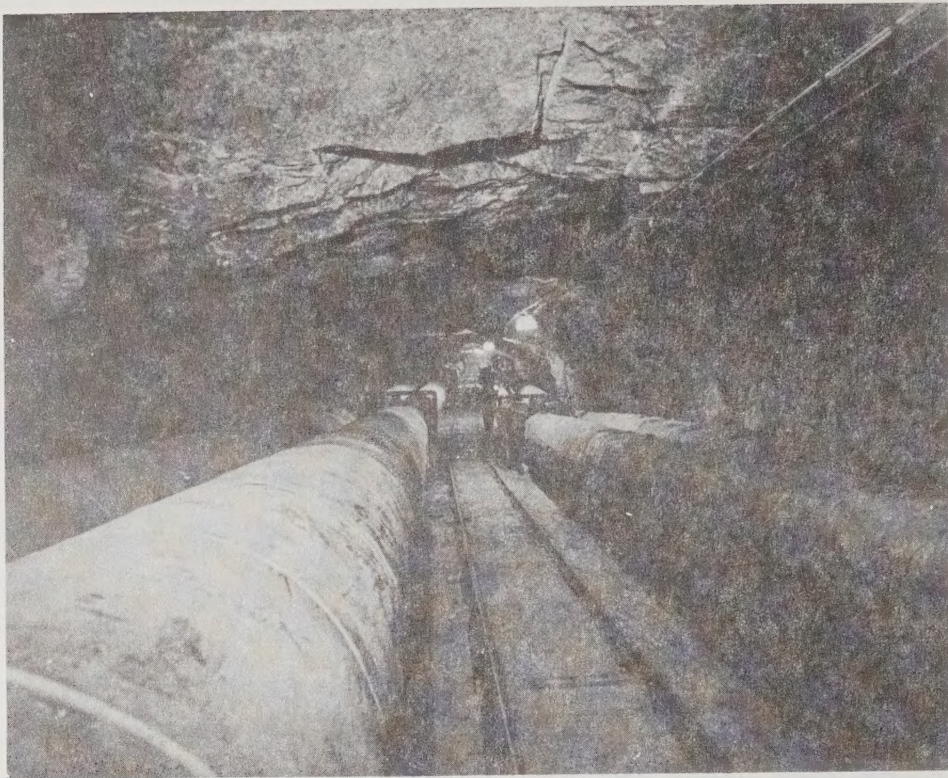


FIGURE 3. MAIN HOT WATER DISTRIBUTION LINES IN ROCK TUNNEL
IN STOCKHOLM

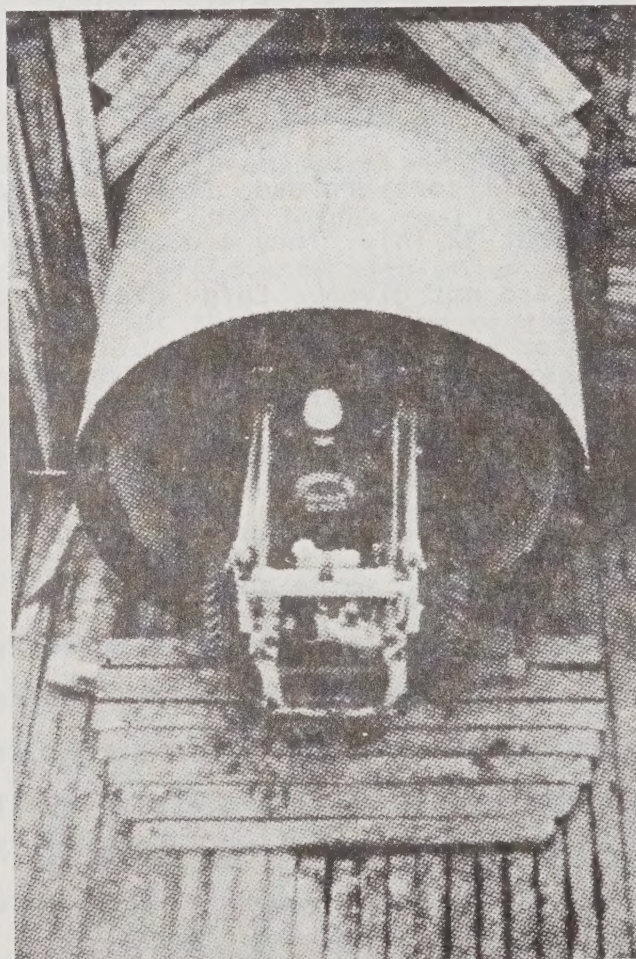


FIGURE 4. PRESSING CONCRETE PIPES UNDER ROADWAY

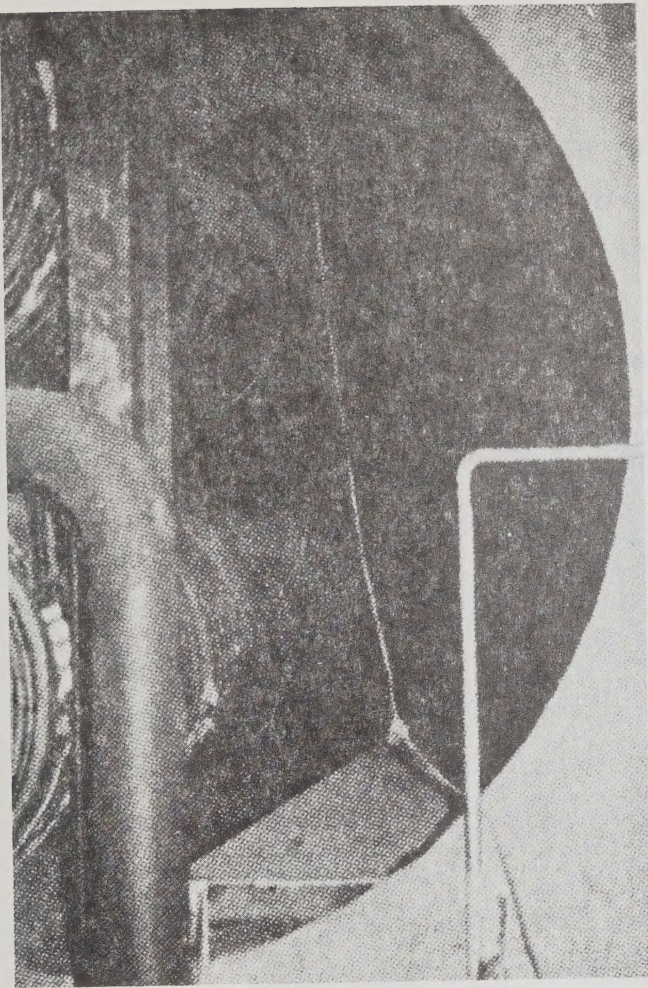


FIGURE 5. 800 mm DIAMETER PIPES
INSTALLED IN CULVERT



FIGURE 6. NEW MAIN SUPPLY LINE
UNDER CONSTRUCTION

Insulated Culverts

In Finland, insulated culverts have come into use for small pipe sizes (50 to 200 mm, 2 to 8 in) which provide a very efficient method of construction. Figure 7 shows a view during installation. The outer conduits are of glass fiber reinforced polyester. The insulating material is high temperature polyurethane foam. Joints of the pre-fabricated insulated culverts are made with heat shrinking plastic sleeves.

Pipe-in-pipe Systems

These field-assembled pipe systems are popular and efficient. They are used for pipe sizes of 25 to 300 mm (about 1 to 12 in). Smaller pipe sizes are installed with two pipes in a common outer pipe, larger sizes are a single pipe with pipe. The outer pipe of asbestos cement with O-ring couplings can be considered to be a small culvert. There is an air space between the outer pipe and the insulation around the inner pipe. Figure 8 shows the typical construction in cross section. There is a drain pipe in the ditch to protect against standing water.

Directly Buried Insulated and Jacketed Pipes

These factory-insulated pipes are used in sizes from 25 to 100 mm (1 to 4 in) for street mains and service lines. They are quick and easy to install and are becoming very popular. The steel pipes are supplied in standard lengths with integral polyurethane insulation and extruded polyethylene jacket. Pipes are joined by welding the steel pipe and filling the insulation gap and sealing it with a heat shrink sleeve. Copper pipes instead of steel are also used. Figures 9 and 10 show an installation of this type.

Flexible Insulated Pipes

Recently a flexible insulated pipe has become available for efficient installation of service lines in sizes from 20 to 50 mm (about 0.8 to 2 in). The pipe is manufactured in long continuous lengths and shipped on a reel like a large cable. It is laid like a cable and can be called "cable-pipe". The inner pipe is corrugated copper tubing, the outer pipe is corrugated steel tubing, the insulation is polyurethane foam and the jacket is extruded polyethylene. Figure 11 shows the construction of this Flexwell pipe and Figure 12 shows its installation.

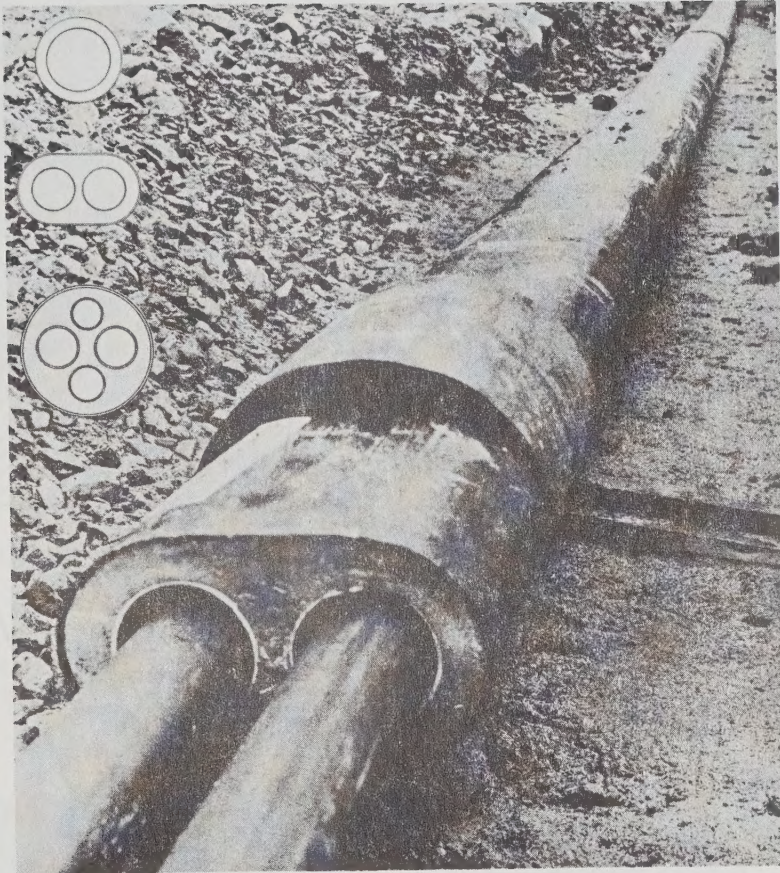


FIGURE 7. FISKARS INSULATED CULVERT ASSEMBLY

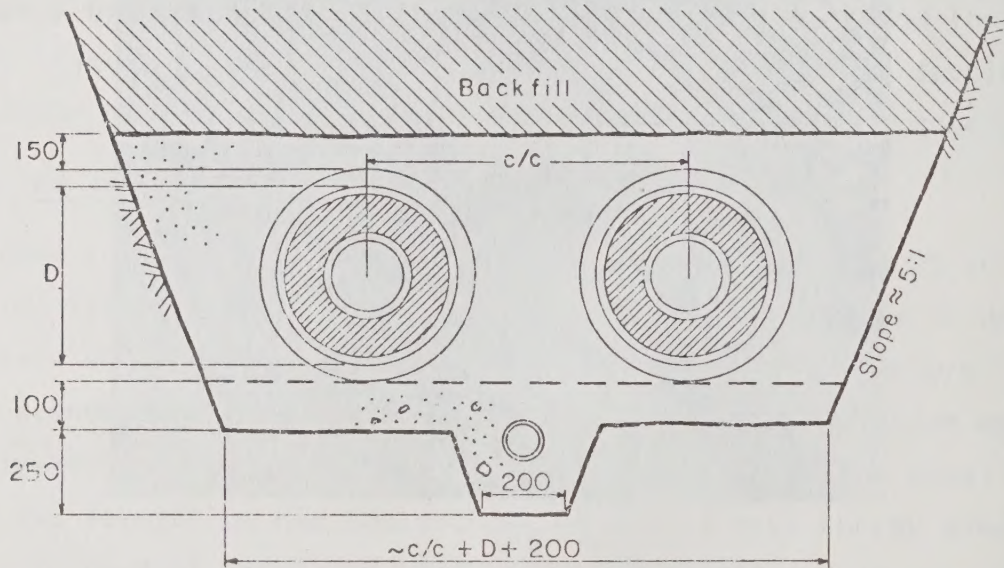
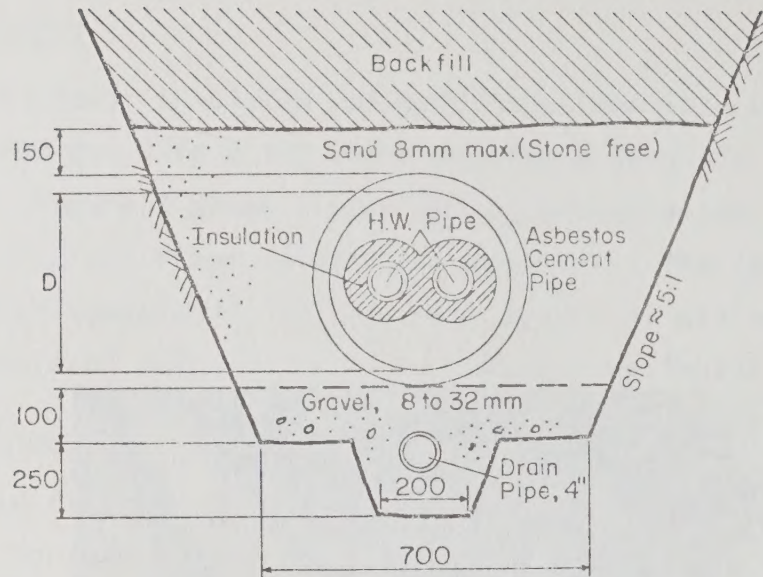


FIGURE 8. TYPICAL SWEDISH HOT WATER PIPE INSTALLATION
IN ASBESTOS CEMENT PIPE, EITHER SINGLY OR IN PAIRS

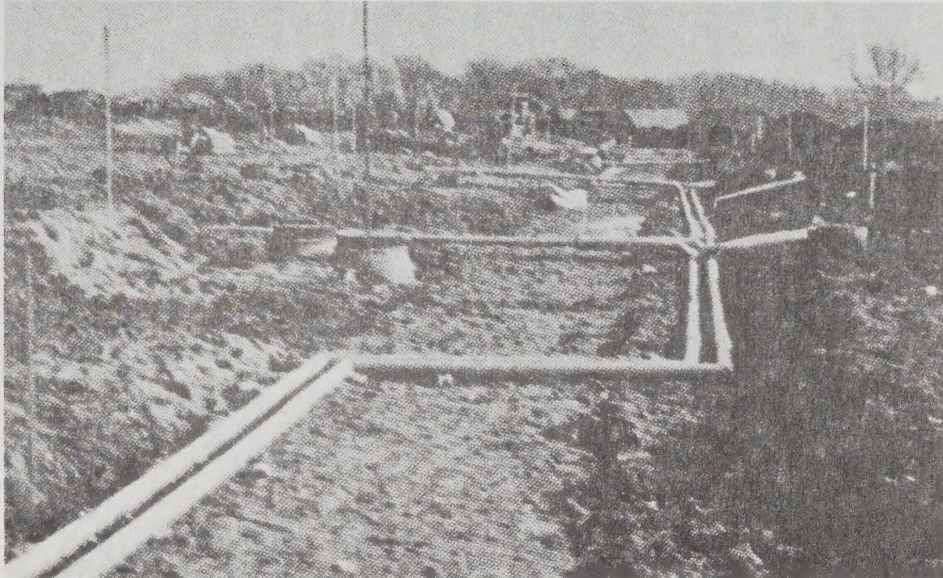


FIGURE 9. DIRECTLY BURIED INSULATED HOT WATER PIPES WITH PLASTIC JACKET DURING INSTALLATION

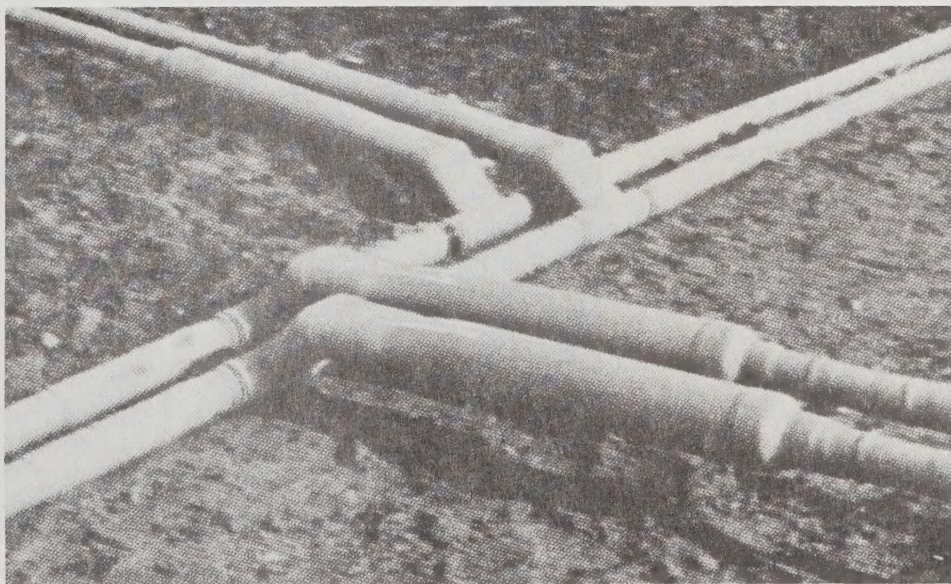


FIGURE 10. CLOSE-UP OF PLASTIC JACKET PIPE CONNECTIONS WITH HEAT-SHRINK JOINT SEALS

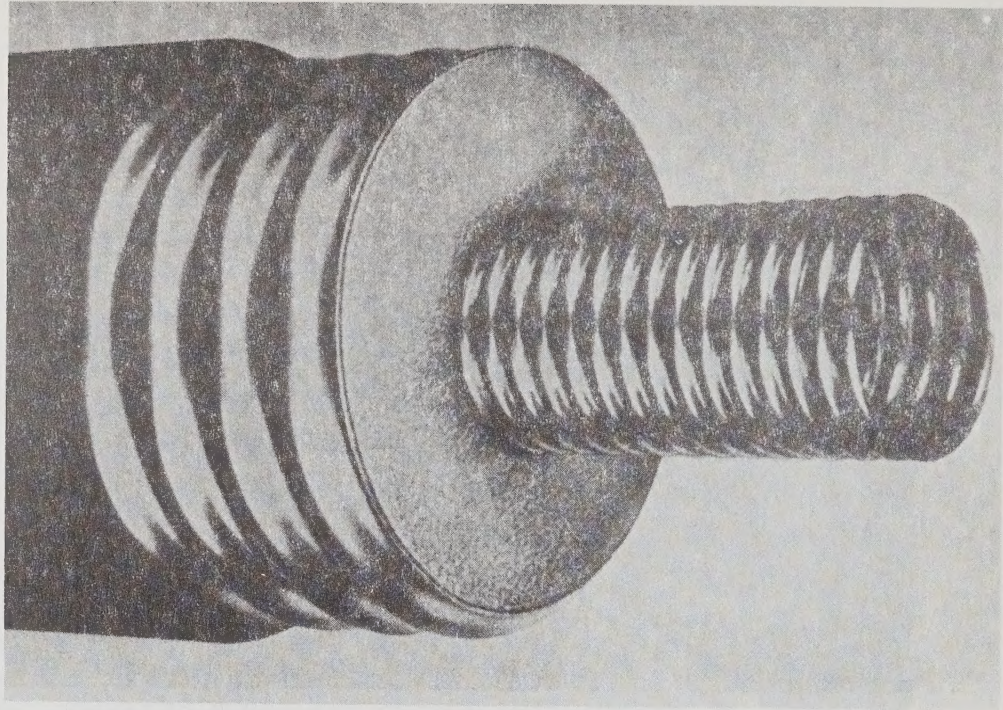


FIGURE 11. FLEXWELL DISTRICT HEATING PIPE



FIGURE 12. INSTALLATION OF DIRECTLY BURIED FLEXIBLE INSULATED PIPE. THIS "CABLE-PIPE" IS PRODUCED IN LONG CONTINUOUS LENGTHS AND DELIVERED ON CABLE DRUMS

Pipes Above Ground

Distribution lines are normally placed underground. Only occasionally are they placed above ground. Figures 13 and 14 show a hot water transmission line in Reykjavik, Iceland. It is a temporary installation and a buried line will be built later. The insulated pipe is covered with an aluminum jacket for protection. Figure 15 shows a main transmission line to the hot water storage tanks in Reykjavik. For long distance transmission, it is usually advantageous to build above ground, as with electrical transmission, too. On the other hand, underground placement of the pipes is preferable for aesthetic and security reasons.

ELECTRIC DISTRIBUTION

Electric transmission and distribution is highly developed technology in Northern Europe as in North America. Technological advances move quickly from country to country. Therefore, there are few surprises or important differences.

It may be noted that it is a general characteristic of Northern European practice to place electric utility lines underground to a greater extent than is common in North America. Underground distribution involves greater installation costs than overhead wires but the reliability is increased and the unsightly appearance of poles and wires is avoided. In open country, the distribution is, of course, overhead and main transmission lines are also suspended from towers, as elsewhere.

There is one development, however, that is starting a small revolution in electrical distribution. Coming from Finland and gaining popularity in Sweden and Norway are self-supporting aerial cables. They consist of three or four insulated, twisted conductors without mechanical support cable and without outer jacket, and they are suitable for service up to 24 kV. Their special advantage is lower cost and greater reliability than bare overhead wires. They are hung from poles with insulated or uninsulated hangers which have shear pins that permit the cables to drop under excessive loads. The cables continue to provide service, even when dropped, without presenting a hazard. Other advantages are low line reactance and relative insensitivity to trees along the right-of-way.

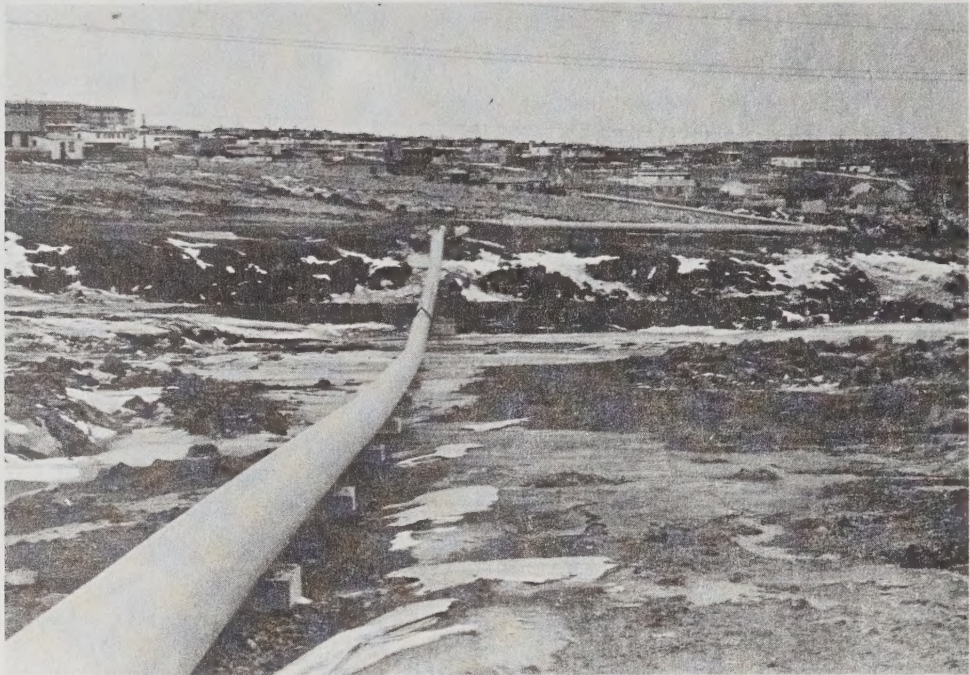


FIGURE 13. TEMPORARY NEW HOT WATER SUPPLY LINE

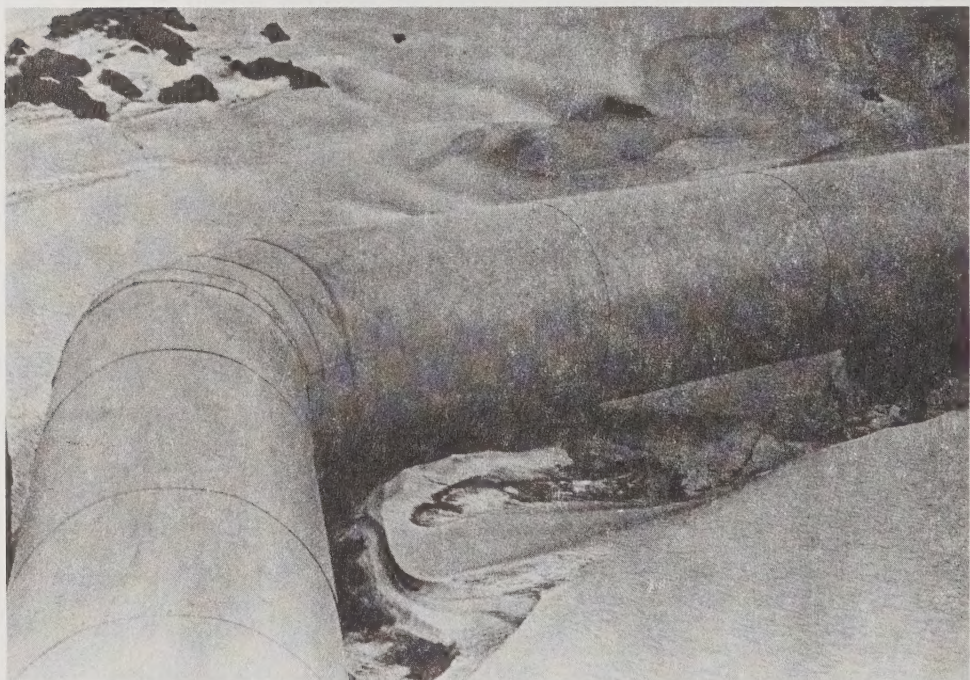


FIGURE 14. CLOSE-UP OF TEMPORARY HOT WATER LINE



FIGURE 15. HOT WATER MAIN SUPPLY LINE AND STORAGE TANKS IN BACKGROUND

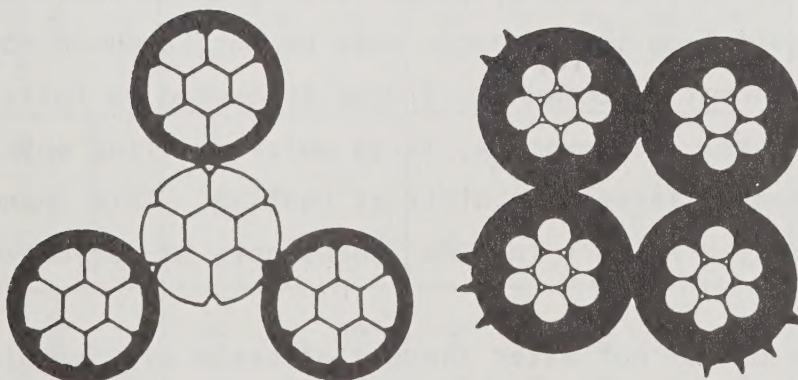


FIGURE 16. CROSS SECTIONS OF SELF-SUPPORTING AERIAL CABLES, FINISH AMKA (LEFT) AND SWEDISH ALUS (RIGHT)

Figure 16 illustrates the cross sections of two types of self-supporting aerial cables. Tables 3 and 4 give details of mechanical and electrical characteristics of Finish cables, type AMKA.

It may seem surprising that this development of aerial cables comes from Northern Europe where underground distribution is valued so highly. Perhaps two of the reasons behind it are that a lower cost alternative to underground distribution cables is desired and that the reliability of distribution is needed particularly in severe weather. As far as the appearance of the cables is concerned, the impression is that the single line looks much less cluttered than the several bare wires.

The self-supporting aerial cables would appear to offer a promising new approach to economical and reliable electrical distribution in Canada and Alaska, particularly in villages and towns.

CONCLUSIONS

Most of the problems facing communities constructed on permafrost are not found in Northern Europe since permafrost is only found in the extremely northern portions of Norway and Finland. However, the pneumatic sewage and garbage systems have inherent advantage in permafrost areas since they eliminate the need for grading of sewage lines and can be run in small utilidors on the surface along the contours of the ground.

Efficiency of energy usage is an area we would do well to study closely and gain from the advances made by our European counterparts. However a different concept in community living is needed to fully capitalize on these concepts. For example, large multi-dwelling apartments that can be efficiently served for district heating. This change in life style may be extremely difficult for the inhabitants of our northern communities to accept.

The use of hot water instead of steam as a carrier for heat distribution is a significant change from past conventional practices in North America. Some good arguments exist for the use of hot water systems which should be evaluated carefully for new communities planning heat distribution systems.

TABLE 3. DETAILS OF THE CONSTRUCTION OF AMKA CABLES.

AMKA (number and cross sectional area of conductors) 2 mm	Insulated conductors					Neutral messenger			Total cable		Delivery	
	Number and cross sectional area mm ²	Number of strands in conductor	Diameter of conductor max. mm	Metal mass kg/km	Insula- tion thickness mm	Number of strands in conductor	Diameter max. mm	Metal mass kg/km	Diameter max. mm	Total mass kg/km	Standard production length m	Type of reel
1 x 16 + 25	1 x 16	1	4.55	50	1.4	7	6.1	70	14.5	140	1,000	D
1 x 25 + 35	1 x 25	7	6.1	70	1.4	7	7.2	100	17.5	190	1,000	D
1 x 35 + 50	1 x 35	7	7.2	100	1.6	7	8.6	140	20.5	270	1,000	E
3 x 16 + 25	3 x 16	1	4.55	130	1.4	7	6.1	70	19.0	270	1,000	D
3 x 25 + 35	3 x 25	7	6.1	210	1.4	7	7.2	100	23.0	390	1,000	D
3 x 35 + 50	3 x 35	7	7.2	290	1.6	7	8.6	140	26.5	540	1,000	E
3 x 50 + 70	3 x 50	7	8.6	410	1.6	7	10.4	190	30.0	740	1,000	F
3 x 70 + 95	3 x 70	7	10.4	580	1.8	7	12.0	260	36.0	990	1,000	F

TABLE 4. ELECTRICAL PROPERTIES OF AMKA SELF-SUPPORTING CABLES.

AMKA	D.c. resistances Ω/km				Inductive reactance at 50 Hz $\Omega/\text{km}/\text{phase}$	Max. permissible current capacity A	Rated current of overload protection A	Max. permissible short-circuit current lasting 1 s kA	Insulation resistances at +60°C minimum $M\Omega \text{ km}$
	phase conductors		neutral conductor						
	+20°C	+65°C	+20°C	+65°C					
2 mm^2									
1 x 16 + 25	1.894	2.237	1.380	1.597	0.083	75	63	1	306
1 x 25 + 35	1.212	1.431	0.986	1.141	0.081	100	80	1.5	242
1 x 35 + 50	0.866	1.025	0.690	0.799	0.080	125	100	2	236
3 x 16 + 25	1.894	2.237	1.380	1.597	0.110	70	50	1	306
3 x 25 + 35	1.212	1.431	0.986	1.141	0.106	95	63	1.5	242
3 x 35 + 50	0.866	1.025	0.690	0.799	0.104	115	80	2	236
3 x 50 + 70	0.606	0.716	0.493	0.571	0.101	140	100	3	202
3 x 70 + 95	0.433	0.511	0.363	0.420	0.098	180	125	4	193

The bulk of normal distribution practices in Europe other than those above were not significantly different and showed little that held much promise or advantage to arctic North America.

SESSION 11

EXAMINATION OF THERMAL CONDITIONS

UNLOCKING THE UTILIDOR:

NORTHERN UTILITIES DESIGN & COST ANALYSIS

by

D.J. Gamble
Consultant
Ottawa, Ontario

INTRODUCTION

The North is certainly changing rapidly. There can be little doubt that oil and gas are the new northern magic. I'm afraid that the importance of providing basic water and sanitation service in northern communities has been almost lost in the frenzy of hydrocarbon developments. So, I'd like to take a few moments to describe, in part, why we are all here today.

Poor sanitation in northern communities was described in a Department of Manpower and Immigration study as one of the major causes of poor health in the north and hence a cause in the unemployment of northerners [1]. Also, statistics from the Department of Health and Welfare show that in the north the death rate per 1,000 births, a key statistic in health, is $2\frac{1}{2}$ to 4 times the Canadian average [2].

A recent investigation of statistics in Wabasca-Desmarais, an isolated largely native community in northern Alberta, shows that the number of hospital days traceable to poor water and sanitation were eight times the provincial average [3]. This community had only rudimentary and sporadic water delivery. A consultant's study of the Wabasca-Desmarais situation quantified the cost of this level of service to the community and the government [4]. It was demonstrated that if the government invested in a completely subsidized trucked water delivery system it would get a net return on its investment of at least 62% considering health costs alone. I'm sure that is the sort of profit that the Anti-Inflation Board would encourage!

This same type of analysis can be done for virtually any northern community given enough data, time and money. But these are motherhood issues. Expenditures on water and sanitation are good

investments that have incalculable multiplying effects that rebound off every aspect of the economic and social fabric of a community.

The Federal Government has acknowledged the importance of such improvements. The first national objective for the north, which is placed before renewable and non-renewable resource development objectives, is:

"To provide for a higher standard of living, quality of life and equality of opportunity for northern residents by methods which are compatible with their own preferences and aspirations." [5]

Countless studies done in this country, the United States and by the United Nations stress that one of the first steps in improving the condition of life for all peoples is the provision of adequate water and sanitation systems [6]. The research has been done. The technology is available. The benefits are indisputable.

What is the problem in the North then? In my view the problem is ineffective uncoordinated government programs and a lack of diligent engineering.

A favorite quip of a Territorial Government Planner is: "If it isn't substandard, it isn't northern". I'm afraid there is some truth in that. There are times when I start to wonder if Monty Python isn't the patron saint for the municipal engineer in the north. Mistakes are perpetrated. Priorities are confused. Vast sums of money are spent with little return and astronomical costs tend to be dismissed with a shrug.

In this paper I'd like to concentrate on a cost and design analysis of utilidors but first I think it would be worthwhile if I put things in perspective by briefly outlining the Northwest Territories Water and Sanitation Policy.

N.W.T. WATER AND SANITATION POLICY

The policy was developed in 1973 by the Government of the Northwest Territories to define its support in methodically upgrading the water, sewer and solid waste systems in northern communities. It was a 120 million dollar ten-year program. The details of the policy are available elsewhere [7, 8, 9], but it is worthy to note that:

"Population is taken as the base factor in deciding the level of service and type of equipment to be provided to each community. However, other factors such as cost of present service, physical characteristics of the size and possible growth of the community are also considered."

The levels of service are shown on Figure 1. These vary, as you can see, from no service at all, to a partially piped system, to a fully piped system. A partial system is defined as a piped water system from the source of water to a centrally located water treatment plant and a sewage disposal facility compatible with current legislation. A sewage outfall line from a central point in the community may be constructed. Delivery to and from the central facilities would be by vehicle with individual houses equipped with sewage pumpout tanks.

Figure 2 shows a schematic for northern water and sanitation systems, the individual components of which when taken collectively define a level of service. The key area is water consumption since it dictates the economics of various distribution systems and hence sewage collection systems.

The problem in implementing the policy was how to determine the level of service to provide to each particular community and when. It is an ongoing assessment problem depending on many factors that vary as the communities' needs change. This is a textbook decision science problem and that was the approach taken.

Based on the components or building blocks of a system as shown in Figure 2, a computer based deterministic model was developed to help implement the policy [10]. The cost associated with alternative systems was assessed as a function of over 100 variables including population, consumption, distance to the water source, community layout and so on. The basis for comparison of the various alternatives is the net present value of the investment required over the duration of the program. It was recognized that the proper theoretical basis for comparison is the net present value of the social benefits that would accrue to the community from each alternative. However, no method has been devised that can handle the interpersonal comparisons of utility involved in determination of the relative merit of, for example, a fully piped system in one community with no facilities in another, compared to a trucked system in both.

NWT. WATER & SANITATION POLICY

LEVELS OF SERVICE

LEVEL	BASE FACTOR	DESCRIPTION
1	Population less than 50	No service provided
2	Population 50 – 150	Tractor and wagon delivery of water and collection of sewage bags
3	Population 151 – 700	Partially piped system with delivery to and from central facilities by vehicle. Homes to be equipped with pumpout tanks.
4	Populations over 700	Completely piped water & sewer

Figure 1

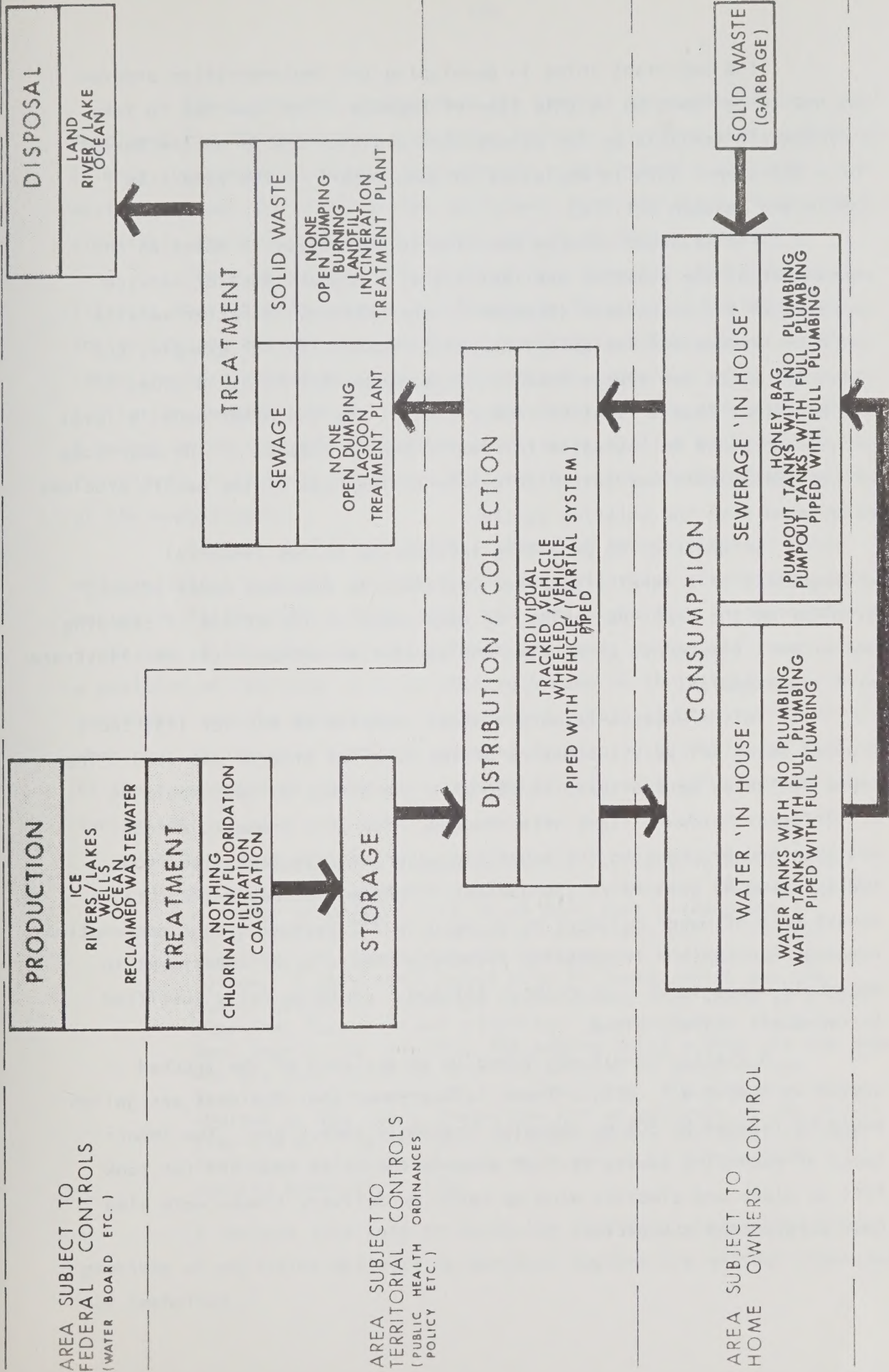


FIGURE 2. WATER AND SANITATION SYSTEM SCHEMATIC

The important thing in developing the implementation program was not to get hung up on this type of impasse. The task was to take a systematic analysis as far as possible and then use it as the basis for a decision. This is explained in some detail in two papers by Gamble and Janssen [11, 12].

The level of service decision in the policy is based on an assessment of the relative desirability of a higher level of service compared to the associated increase in expenditure. A better service could be recommended for purely economic reasons if, for example, the volume of water and sewage makes it more economical to use a piped system rather than a fleet of tanker trucks. On the other hand, a level of service could be increased for public health reasons if the magnitude of the expenditure was justified by the seriousness of the health problems associated with the existing system.

In addition to providing information on the financial consequences of a level of service decision the computer model allows, by altering the input variables, an assessment of the effect of changing one or more components of a water and sanitation system. Let me illustrate with two examples.

In the Wabasca-Desmarais study referred to earlier [13] the trucked water delivery subroutine of the computer program was used. The input variables were altered to see what the effect on cost would be if different hardware items were changed. The most dramatic effect was obtained by changing the household water storage tank size from the existing 45 gallons to 250 gallons. This would reduce the total annual cost of water delivery by as much as 72% (assuming that consumption remained constant). It appeared therefore that a major investment in household water tanks - as much as \$41,000 - could be fully justified for economic reasons alone.

A similar result was found in an analysis of the trucked system in Rae, N.W.T. [14]. There it was shown that the cost per gallon could be reduced by 50% by changing household tank sizes. The importance of such time saving devices as exterior quick couplers for tank fill up pipes and electric wind up reels on delivery trucks were also demonstrated and quantified.

These examples demonstrate the general approach that was developed for the water and sanitation policy. It shows that a decision science, operations research approach can - and indeed must - be applied to make the right design decisions. The off-the-cuff type of simplistic analysis so common in the past is no longer acceptable.

There is a Catch 22 situation here however. The Federal Treasury Board failed to give the long-term financial commitment to the policy and instead, approved it in principle only. Also, it has taken the Territorial Government two years to recruit a water and sanitation co-ordinator to implement the program. So, again this year a budget which I'm told approaches about eight million dollars will be "invested" in projects without a full appreciation of the effectiveness of the expenditures.

Perhaps a more significant aspect of the Territorial water and sanitation programs relates to the centralization of the decision-making in Yellowknife. Quite often the people who live in the communities - the people for whom the improvements are meant to benefit - are only in a position of reacting to basic decisions made on their behalf by the government and the governments consultants. This is of vital importance when considering utilities delivery, as documented by White and Seviour in their synopsis of the costs and benefits of rural water supply and sanitation:

"There has been a pronounced shift in thinking about rural water supplies and sanitation during the past 20 years, from a rather simplistic view which held that disease was a major constraint in developing countries, and if it were lessened, increased economic development would inevitably follow. A more complicated view followed, which saw the social system in which the water system took shape as a very important factor in any planning. A more recent shift has been toward the view that the people being served are the ones who are most capable, with assistance, of choosing the levels of improvement they can best use. Systems involving choices by the users themselves and an analysis of the risks they are willing to take, weighed against the benefits they feel they will receive, are more likely to bring them lasting benefits." [15]

I include this only to emphasize that many of the most basic problems of utilities delivery in northern regions are neither financial nor technical.

UTILIDORS

A major weakness in the technology of northern utilities delivery is in the area of utilidor systems. I'd like to use the balance of this paper to show how cost and design analysis similar to those of the Water and Sanitation Policy implementation program may be used to solve many of the technical problems associated with utilidor engineering and planning. I have divided this discussion into four parts - community layout, piping design, design standards and prefabrication. Inuvik will be used as my main example because that is where I've been able to get the best data. Inuvik is also the 'test-bed' for utilidors with eight different designs in use.

Implicit in my analysis is that quite unconsciously we have been designing utilidor systems without thoroughly examining our southern design biases. Also, we haven't analysed that we have done carefully enough to evaluate where to go next. Without reviewing these two things, I don't believe that we will be able to economically improve the water and sanitation services in northern communities.

Utilidors and Community Planning

Community layout is a logical first place to look in an analysis of the cost of piped service.

Community layouts reflect the cultural patterns of northern settlements. In their book entitled "Arctic Townsman", John and Irma Honigman have differentiated three major cultural periods which they term the Formative Period, the Fluorescent Period and the Period of Planned Development [16]. Northern community plans have evolved through several generations in a roughly parallel fashion. The first generation was the typical scattered, haphazard town so often seen in frontier areas. The second generation was a planned community but largely based on southern towns. The third generation began to face up to the reality that northern towns don't need large lawns, long driveways, wide squares etc. In towns such as Frobisher Bay and Inuvik, town planning suitable for a hostile climate started to appear. The planning of communities like Fermont in northern Quebec are seen as taking that process one step further to the fourth generation of arctic communities [17].

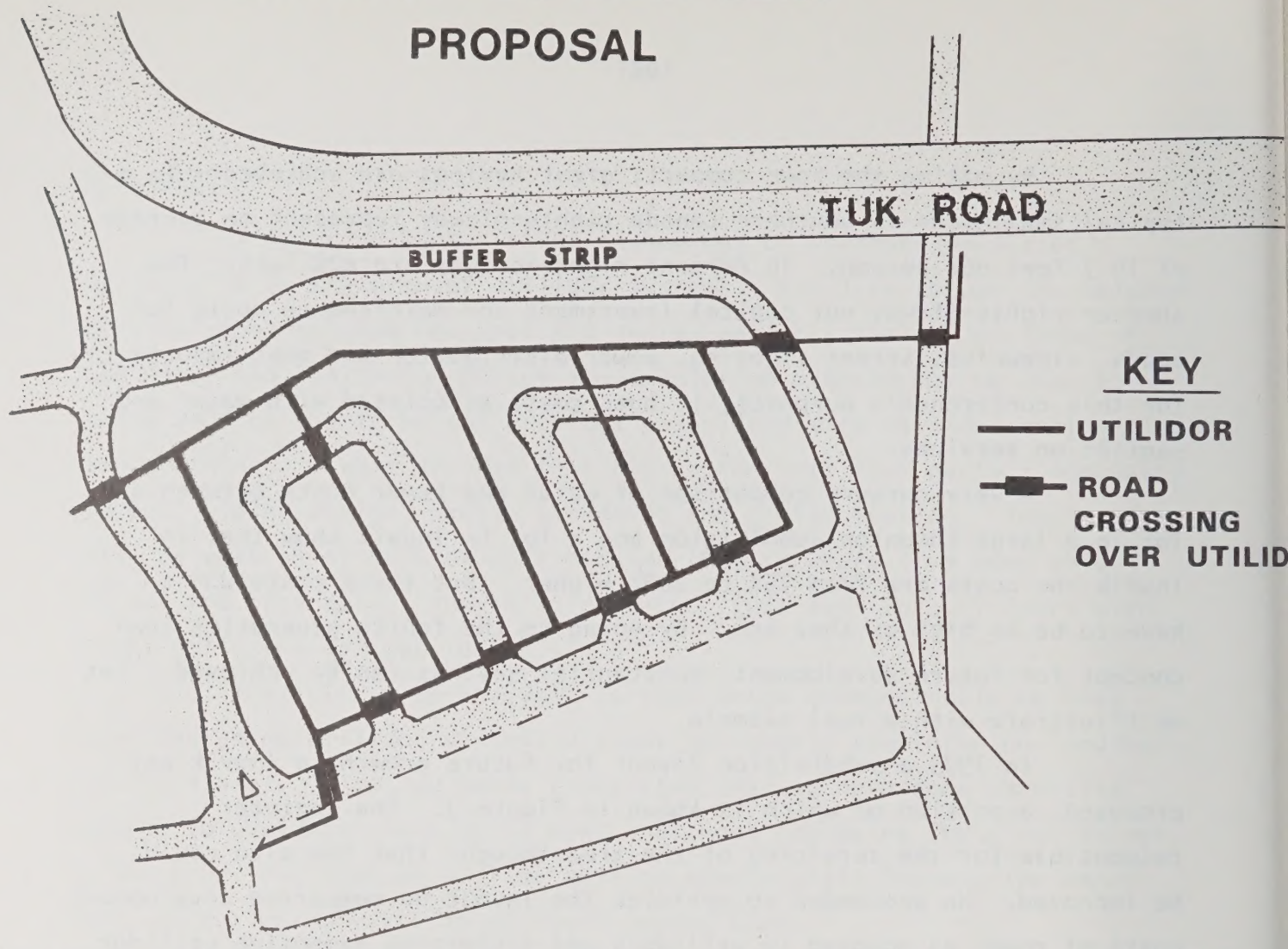
By making the town compact, great savings are achieved. In a typical small town in southern Canada rights-of-way represent an average of 19.7 feet per person. In Fermont rights-of-way are 62% less. The shorter rights-of-way cut capital investment and maintenance costs for roads, sidewalks, street lighting, power distribution and most importantly for this conference's purposes, it cuts costs associated with water and sanitation services.

A very cursory comparison of water and sewer costs between a lot in a large Edmonton subdivision and a lot in Inuvik show that in Inuvik the costs are from 75% to 200% higher. But these costs don't have to be as high as they are. By going to the fourth generation town concept for future development, substantial savings can be achieved. Let me illustrate with a real example.

In 1973 a subdivision layout for future growth in Inuvik was proposed, a portion of which is shown in Figure 3. The engineer responsible for the servicing of the area thought that the plan could be improved. He proceeded to optimize the layout by comparing development costs of roads as opposed to utilidors and minimizing expensive utilidor road crossings. Figure 4 shows the resulting plan. Table 1 shows the net savings achieved by the improved design. The saving achieved on the illustrated portion of the subdivision was \$240,000 (in 1973 dollars). That represented 15% of the development's capital cost. It hasn't been built yet - it, like everything else, seems to be awaiting the pipeline - but when it is built the apparent saving will be substantially more because of inflation. Not only will the town realise a one time saving of close to one quarter of a million dollars, but it will continue to save because of the decreased annual costs associated with utilidor and road maintenance.

The obvious question is, why is this sort of analysis not done more often? The development plans for Frobisher Bay, Rankin Inlet, Inuvik and Norman Wells are proof that this sort of rigid cost analysis of community layouts is not being done consistantly. In my view it is haphazard and sloppy design. It leads to excessive costs, which in turn diverts limited government funds away from improving services in other locations. It places crushing financial burdens on individuals

ORIGINAL DEVELOPMENT
PROPOSAL

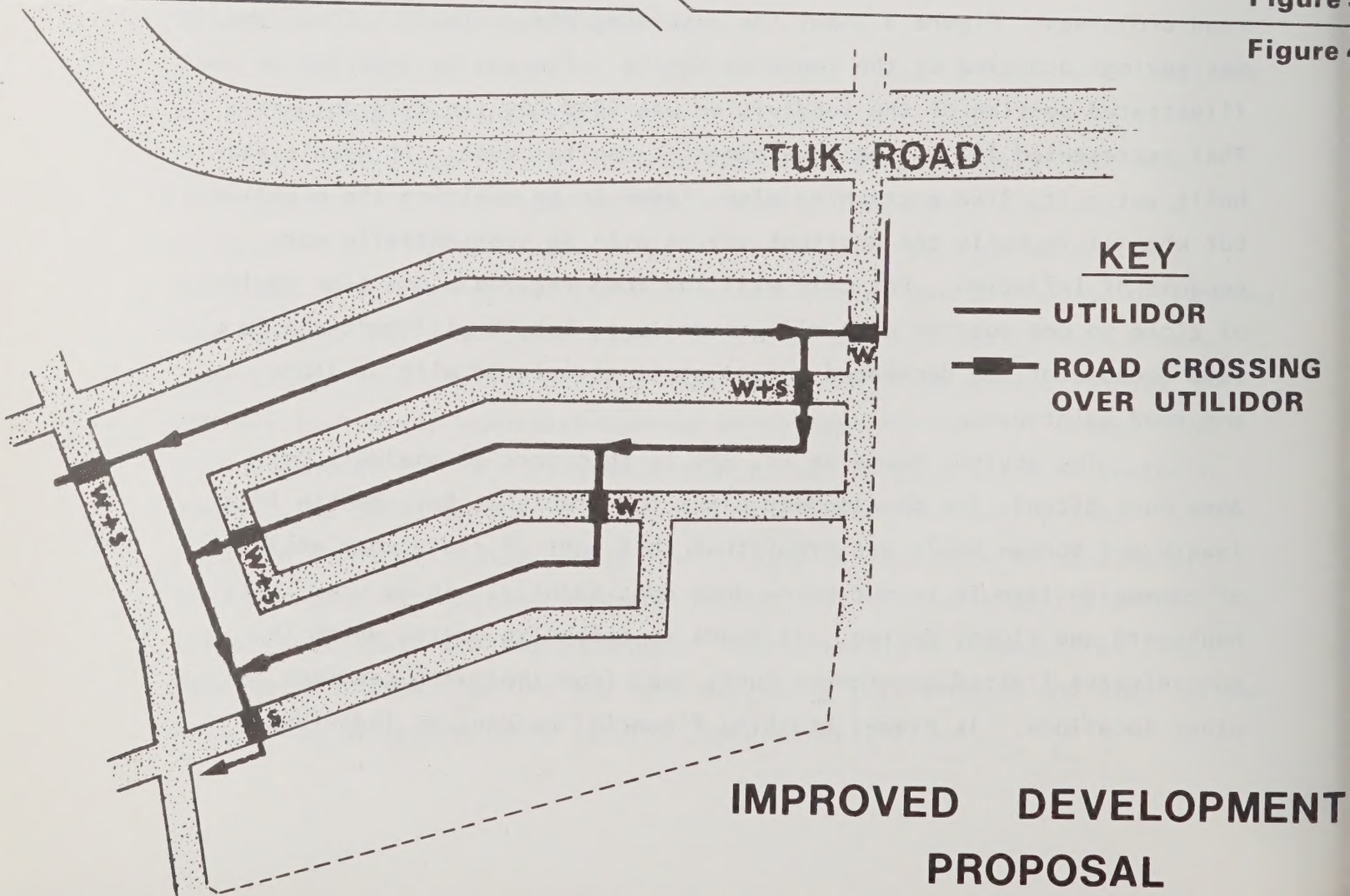


KEY

- UTILIDOR
- ROAD CROSSING OVER UTILIDOR

Figure 1

Figure 2



KEY

- UTILIDOR
- ROAD CROSSING OVER UTILIDOR

IMPROVED DEVELOPMENT
PROPOSAL

NET SAVING OF IMPROVED DEVELOPMENT PROPOSAL

NET SAVING
(1973 DOLLARS)

ITEM	ORIGINAL	IMPROVED	DIFFERENCE	NET SAVING (1973 DOLLARS)
LENGTH OF NEW ROADS	6350	6190	+160	3,000
UTILIDOR LENGTH	6290	5400	+890	109,000
ROAD CROSSINGS	10	6	+ 4	40,000
WATER SYST. LOOPS	4	2		2,000
APPROX. LOTS	140	152	+ 12	84,000
JUNCTIONS & BENDS	12	11	+ 1	2,000
TOTAL				\$240,000

Table 1

and governments. Instead of crying for more and more money we, as designers or administrators, should be concentrating on spending what we do have more efficiently.

Just because a project is north of the Arctic Circle, I think we tend to accept high cost without question. That, of course, is nonsense.

Diligent community planning analysis takes time and can get quite complex. I have had preliminary conversations with a management consulting firm specializing in computer applications to decision science problems [18]. There seems to be a very clever way to use a digitizer with a control computer program for engineering and cost restraints to give a "first cut" on optimum development layouts. This could be a tool in realizing substantial cost savings and I think the idea should be pursued.

The Basis for Piping Design

I hope none of you choose to quarrel with the formulas for pipeline hydraulics. These I accept as given but that is where we should start from when we examine how we unquestioningly transfer our southern design bias north.

The first two things that face a designer are the provision of adequate water for consumption and fire fighting.

The forecast of water consumption is complex for northern communities because of the lack of adequate records, the wide range of levels of service provided within a community and the effect of poor design. Poor designs in Inuvik lead to people running cold water for long periods because it is heated excessively by the central heating system in the utilidor. Poor designs throughout the north lead homeowners to keep water running throughout cold periods so their services don't freeze up. The end result of all this is that the engineer examining the data is forced to guess at what the true consumption is.

This leads to some rather peculiar "socio-engineering" edicts by designers. The most astounding one that I've heard is that consumption is related to racial origin - i.e. Indians and Inuit use less water than others. Well, without belabouring the point I'd like to lay this to rest by quoting from a recent report on Aklavik.

"Examining the water delivery records for 1974, it becomes obvious that the key determining factor in the per capita water consumption is the availability of facilities to use water. People occupying houses equipped with plumbing systems including bathtubs, showers, sinks, etc. invariably use much more water than people having none of these facilities... It should be mentioned that in addition to being dependent on the availability of water utilizing facilities, the rate of water consumption depends on the degree of overcrowding in the dwellings. People in overcrowded dwellings tend to use less water." [19]

Now, this isn't an outstanding piece of news. It is what one would expect. The fact is that the people without facilities and in overcrowded homes are Inuit or Indian. It is interesting to speculate that perhaps water consumption is kept artificially low by designing systems that make use of water difficult - a self-confirming design assumption. I'm sure that this is the sort of approach that gives public health officials in the north insomnia.

The Territorial Water and Sanitation Policy does establish quotas which will be of assistance as a design base. There are many, like myself, who argue with these quotas, but at least it's a start. Slowly better data is becoming available so I think the problem is on its way to solution.

Designing for fire flow is quite another problem. The starting point for designers are the requirements of the Insurance Advisory Organization (IAO). These fire flow and storage requirements invariably dictate the size of the water supply systems in northern communities. In many northern communities - particularly those with trucked delivery systems - the I.A.O. requirements aren't met. A best judgement is made by the designer - more often than not without consultation with the Territorial Fire Marshall's office.

The small communities in the north pose an interesting problem in this regard. Using the Aklavik and Wrigley alternate design decisions as examples, it is apparent that for populations of less than 300, water required for fire fighting purposes may represent 85 to 95% of the total storage provided. These percentages reflect the high cost of meeting present fire fighting standards by the use of the water system. The irony of the situation is that often the limited deliverability of the water (by tanker truck) renders the provision of fire storage somewhat academic.

In the larger communities where piped systems are more prominent, the fire flow requirements inevitably dictate the size of the mains and storage capacity. This in turn is reflected in the cost of the system.

I question the whole concept of designing for fire flows in the north. Systems are oversized to fight fires at a substantial cost. It is my thesis that alternative and more effective means of fighting fires can be developed at a cost significantly less than now incurred. I don't have the definitive solution but let me explain what I've found from a quick examination of the subject.

Over the six-year period 1970 to 1975 there were 1,582 fires in the Northwest Territories resulting in a total financial loss of \$12,037,500. Table 2 shows a compilation of the Territorial Fire Marshall's statistics for that period [20]. It illustrates the percent of fires by cause and the percent of financial loss by cause for the six year period. It is quite apparent that heating devices account for the greatest number of fires (30%) and the greatest financial loss (31%). This is followed by electrical devices, smoking and matches and petroleum products as shown. Over the six year period residential fires accounted for 62% of all fires and 36% of the financial loss. The Territorial Fire Marshall's office advises that 75% of all fires occur in winter - late October to early May [27].

These statistics give some insight into practical design solutions for fire protection in northern communities. As the Fire Marshall's report stresses: "Fire protection and safety features must be engineered and designed into buildings." Why is it not mandatory for all northern buildings - particularly residential buildings - to have smoke and heat detectors? Why is it not mandatory to have a sprinkler installed in the furnace room? The water required to operate a small sprinkler is considerably less than that necessary if the fire gets hold and has to be extinguished with fire hoses, which, in turn, require large diameter piping and large storage. Smoke and heat detectors could provide an early warning. Sprinklers could provide an effective first line of fire fighting service with backup protection provided by other means.

FIRES IN THE NORTHWEST TERRITORIES

1970 to 1975 (inclusive)

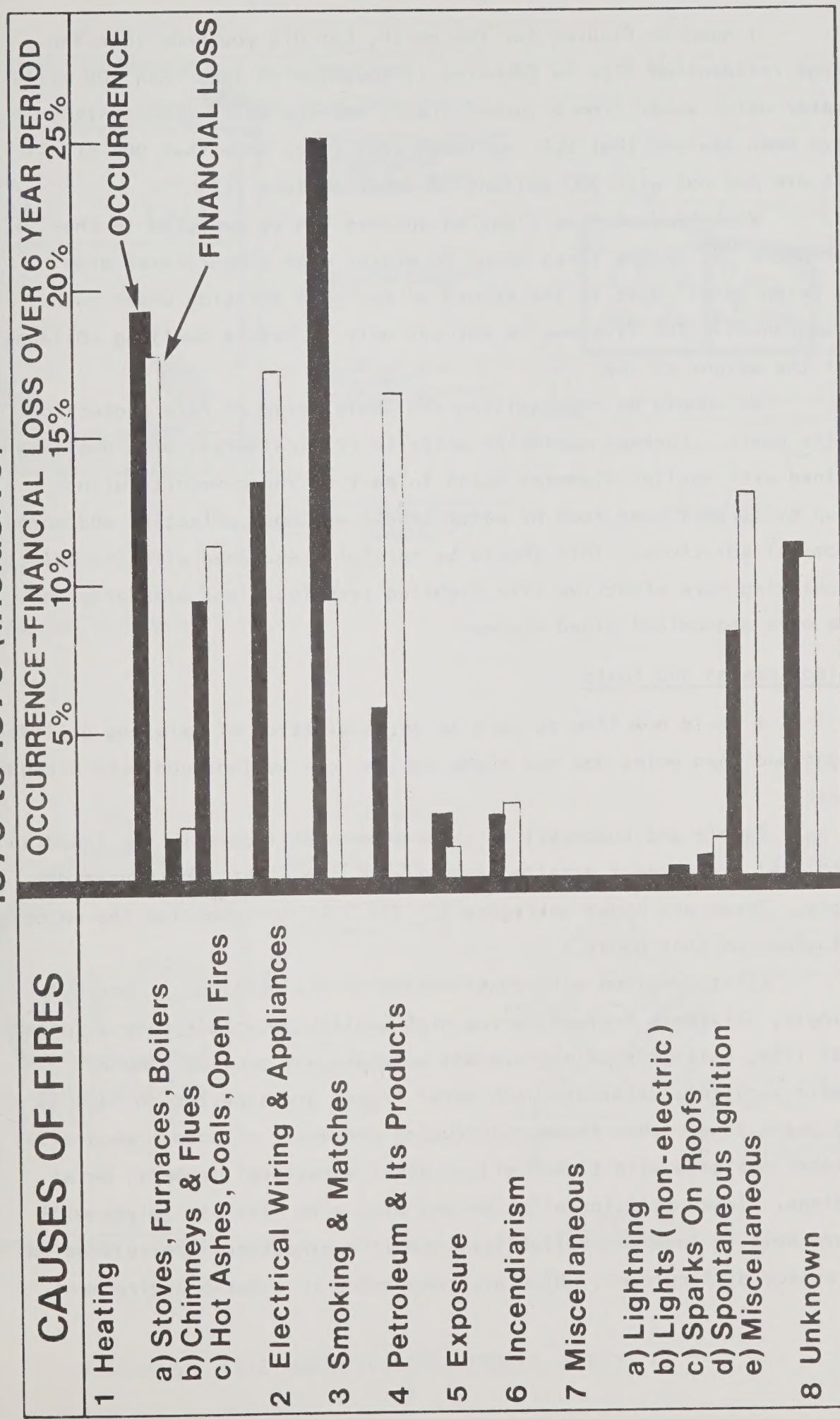


TABLE 2

I have no figures for the north, but did you know that the average residential fire in Edmonton is fought with less than 400 gallons of water using water from a tanker truck, not the mains [22]. Also, I have been advised that U.S. national statistics show that 90% of all fires are put out with 200 gallons of water or less [23].

What kind of fire fighting success can be expected in the north where 75% of the fires occur in winter when temperatures drop well below zero? What is the record of saving a building under such circumstances? The fire may be put out only to have a dwelling collapse under the weight of ice.

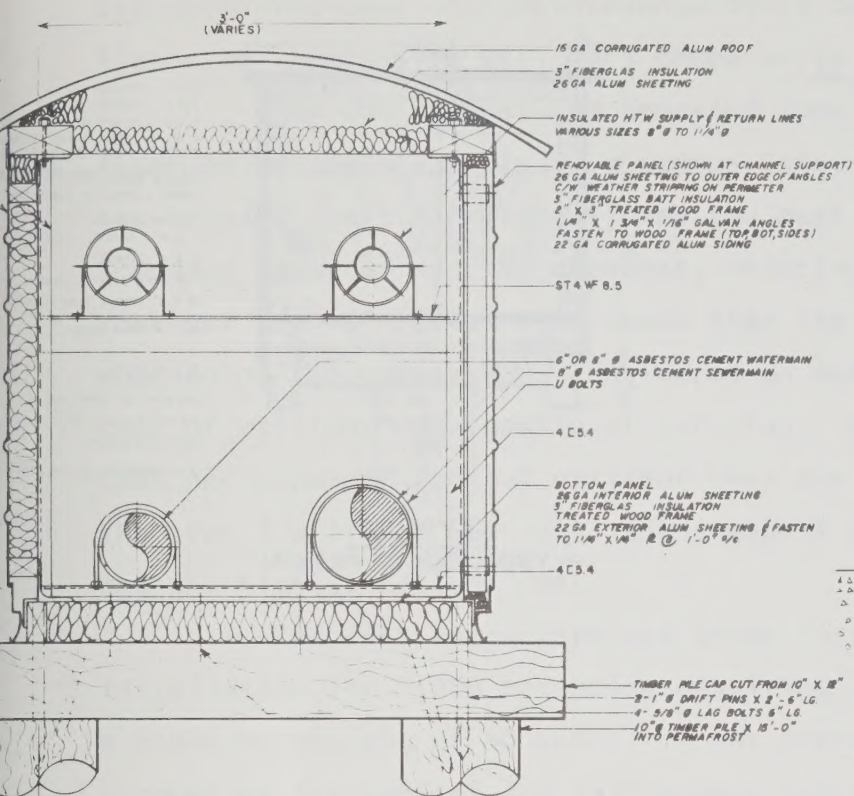
We should be re-examining the whole issue of fire protection and its costs. Perhaps sprinkler units in critical areas of a dwelling combined with smaller diameter mains in part of the community with backup by airport type foam or water trucks are more effective and more economical solutions. This should be carefully examined with the object of achieving more effective fire fighting techniques and standards and hence more economical piped systems.

Utilidor Design and Costs

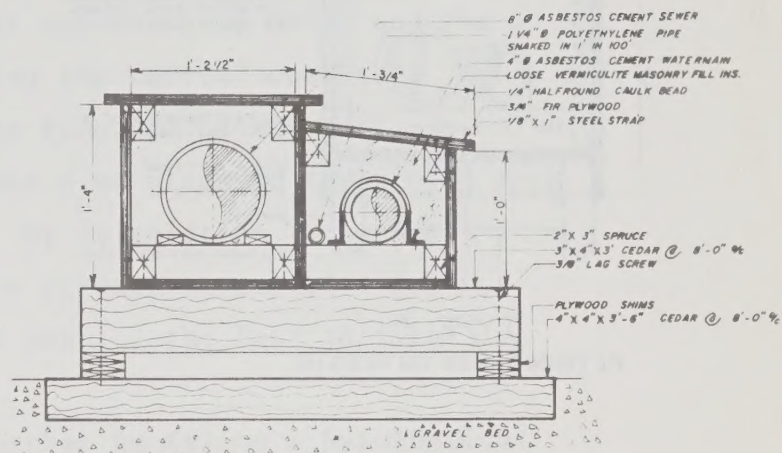
I would now like to turn to an examination of existing utilidor designs and then point out how these designs can be improved with a reduction in cost.

Gamble and Lukomskyj in their paper "Utilidors in the Canadian North" [24] presented a detailed analysis of the eight Inuvik utilidor designs. These are shown on Figure 5. I'd like to summarize the major conclusions of that paper.

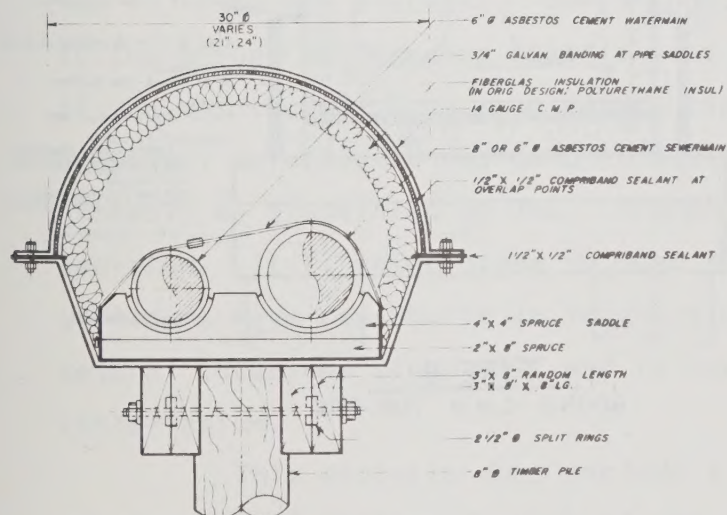
First, dealing with construction of the utilidors. Not surprisingly, utilidors designed using high quality materials have a longer useful life, cost less to operate and maintain and provide a more reliable service. Utilidors with metal frames are expected to last 15 to 20 years longer than those constructed primarily of wood. Generally, utilidors designed with timber piles, steel structural members, metal claddings, closed cell installation and pipe with flexible joints will perform best in Inuvik. Reliability and life expectancy are related to maintenance difficulties, which are compounded in a harsh environment.



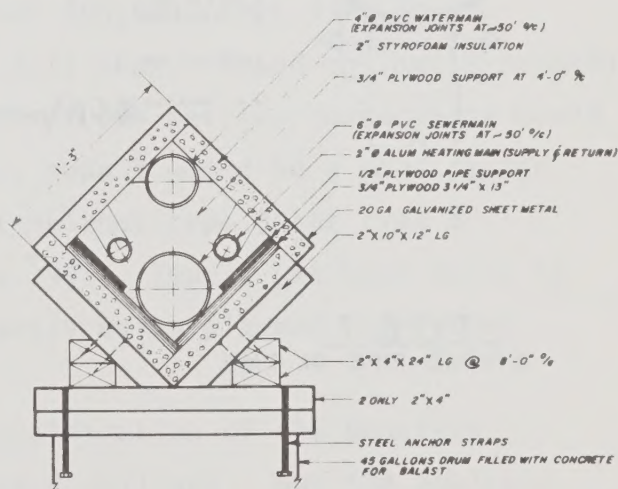
TYPE 1
ORIGINAL UTILIDOR



TYPE 2
PLYWOOD BOX ON FILL

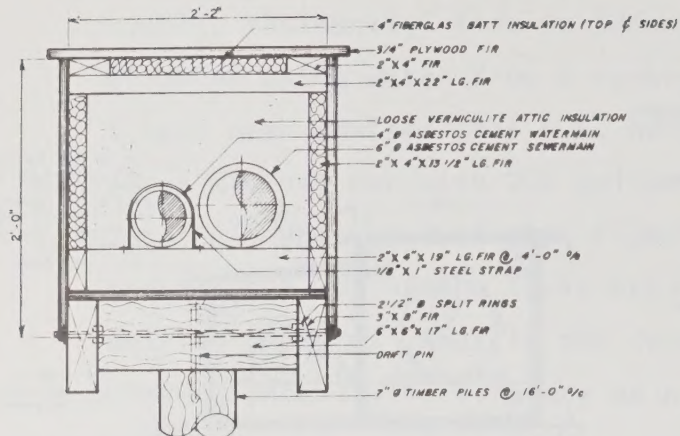


TYPE 3
CORRUGATED METAL PIPE



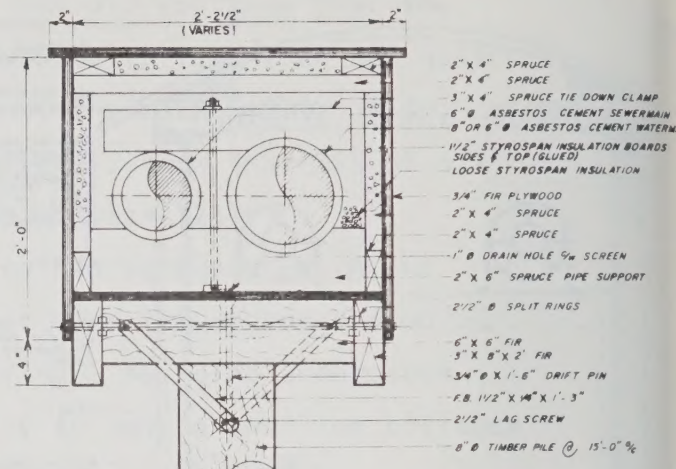
TYPE 4
ECONODOR

FIGURE 5. EXISTING UTILIDORS, INUVIK, N.W.T.



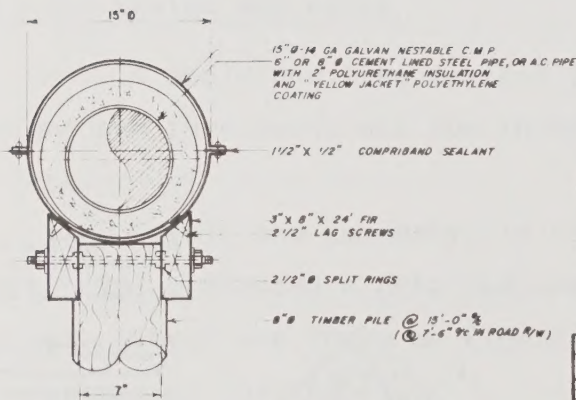
TYPE 5

PLYWOOD BOX ON PILES (a)



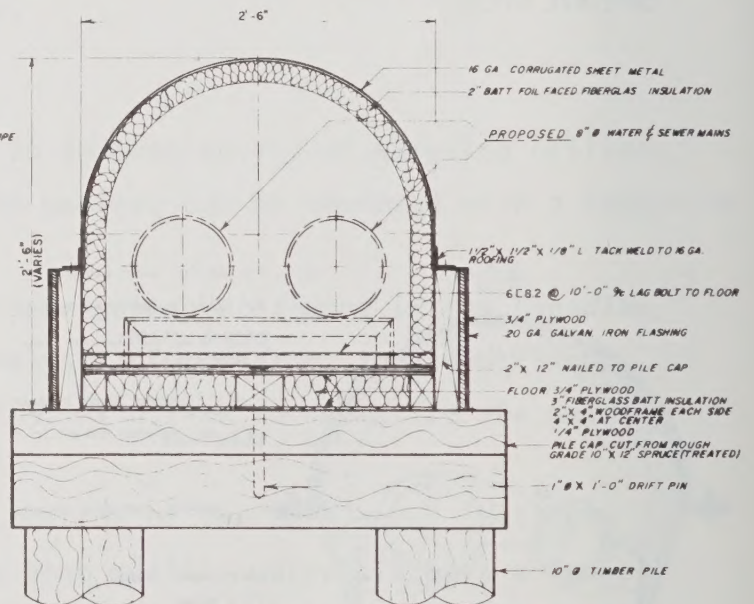
TYPE 6

PLYWOOD BOX ON PILES (b)



TYPE 7

SINGLE PIPE IN C.M.P.



TYPE 8

ROUND C.M.P. TOP BOX

FIGURE 5 (CONT'D).

Estimates indicate that maintenance costs can be up to three times higher on inexpensive utilidors compared to high capital cost utilidors.

The cost comparison revealed some interesting information. After adjusting all costs to a common base, it was apparent that although the original utilidor (type 1) was the most expensive to build and the Econodor (type 4) was the cheapest, reducing the capital cost to a cost per year of useful life shows that the Econodor is the most expensive. When doing the comparison, consideration was also given to the piping each type of utilidor was capable of carrying. By calculating the annual cost per pipe per foot of utilidor over the structures useful life, the type 1 utilidor was still the cheapest despite the fact that it had the highest capital cost.

The cost comparison was taken further by taking a hypothetical installation for 1,000 households requiring 10,000 feet of utilidor with a planning horizon of 40 years. A net present value analysis was done, accounting for capital and maintenance costs, inflation and opportunity costs [25]. The results are shown on Table 3 [26]. The maintenance costs for types 5 to 8 were not quantifiable except as low and average as shown.

Clearly, for the hypothetical installation type 3 is cheaper than types 1, 2 and 4. Type 8 is cheaper than types 5 and 6 (because low is less than average). Comparing 3 and 8 it becomes clear that if the annual maintenance cost is less than \$50,913, type 8 is best. If the maintenance cost is greater, type 3 is best. Based on Inuvik records, an annual maintenance charge of \$50,913 for 1,000 service connections would probably be classified as low. Therefore, type 8 would be a good design decision. It is interesting to note that neither type 3 nor type 8 utilidors have been built in Inuvik since 1971. Type 6 has been built in several locations since 1972 and is currently being planned for future installation.

This analysis does exclude a consideration of the benefits of the central heating feature of the type 1 utilidor. But the analysis as done gives the sound basis upon which rational choices can be made. A decision on a central heating plant versus individual furnaces or whatever is simply another facet which can now be added into the analysis.

COST COMPARISON INUVIK UTILIDOR DESIGNS

TYPE	CAP. COST /FT. 1974	MAINTENANCE COST / YEAR /SERVICE	USEFUL LIFE (YEARS)	NET PRESENT VALUE \$000	ANALYSIS
1	304	34	40	3,950	N/A ↓ TYPE 3 ↓ CHEAPER
2	44	68	10	3,105	
3	105	57	20-25	3,236	
4	51	91	3	7,136	
5	87	AVERAGE	10-15	2,541 + A X F	TYPE 3 - TYPE 8 ↓ \$1,362,464 - L X F N/A ↓
6	115	AVERAGE	13-15	2,630 + A X F	
7	69	LOW	25	1,076 + L X F	
8	115	LOW	20-25	1,873 + L X F	

Table 3

The point I'm trying to make is that this type of analysis is apparently not done by engineers or planners to evaluate designs. Like the community layout issue I discussed previously, the modus operandi seems to be to bull ahead with some kind of eternal optimism that things will turn out all right and money will be forthcoming for whatever rolls off the drafting tables.

I remember being told while I was a student that anyone can build things but it takes an engineer to build at reasonable costs. Are utilidors costing 150 to over 300 dollars per foot reasonable? \$150 per foot is about 115% more than water and sewer services cost in the Edmonton area. The cheapest utilidor in Inuvik is 276% more expensive per foot than the Mackenzie Valley Highway built in the Delta. At \$300 per foot, the large Inuvik utilidor is equivalent to what you would pay per linear foot for a Chevrolet Monza 2 plus 2 or a Ford Mustang. It is cheaper to buy these automobiles and park them bumper to bumper than it is to build the type 1 utilidor in Inuvik. Somehow, I don't think the northern communities are getting their money's worth!

I think we have to start engineering utilidors and not be content just to build them.

Utilidor Design Standards

If we are to engineer utilidors we must develop appropriate design standards based on previous experience. I have mentioned the new approach I think is necessary for water consumption and fire flows. Now let's look at the details of the utilidor itself. Again, this requires a rethink - not simply a transfer of southern water and sewer concepts. Let me illustrate with several examples.

1. Icing inside one utilidor in Inuvik was found to be a problem shortly after its construction. The design was basically sound but the allowable leakage permitted when testing the piping was based on standards used for buried systems in the south. The pipe joints and fittings were also specified using an AWWA spec that permits a certain leakage. Such leakage is not permissible for utilidor piping.

2. Some utilidors in Inuvik and Norman Wells have used vermiculite insulation that has, not surprisingly, acted like a sponge and soaked up water from rain, melting snow and pipe leaks. The insulative properties were thus reduced to nearly useless levels and massive ice froze the inside of the utilidors tight. The next summer workers were seen diligently removing the soggy oatmeal-like vermiculite as well as blocks of a frozen vermiculite and ice conglomerate. But in Norman Wells they replaced it with more vermiculite! The next winter freezing problems were experienced again. I'm told that in desperation fibreglass batt insulation was installed. The literature shows that only 8% water by volume cuts the insulating properties of fibreglass in half so I expect the problem continued despite all the effort and money expended.
3. Large cast iron fittings designed for underground use appear in many utilidors. Not only are they heavy and difficult to insulate, they require major thrust blocking that has to be supported in, or adjacent to, the utilidor.

If we are going to transfer southern standards north then we should be copying the right thing - piping systems inside buildings. We should be looking more at the Plumbing Code and not limit our standards to the AWWA specs. This makes economic sense as well. For example, a butterfly valve which is perfectly acceptable in a utilidor costs 12 to 44% less than a comparable gate valve and weighs 3 to 4 times less. A utilidor hydrant built like a building fire stand pipe is more compact, lighter and easier to keep thawed than a conventional hydrant. It also costs about 18% less. I will show an example of this type of hydrant in a moment.

To summarize, what we need to do is establish uniform design standards and performance guidelines for utilidor installations in the North. These guidelines must address, among other things, the following:

1. the minimum insulation properties including water absorption and the deterioration of thermal conductivity with time;
2. the maximum acceptable rate of heat loss under power out conditions for a specified time, i.e. the weakest spot thermodynamically must be able to remain functional through specified time period under worst case ambient conditions;
3. the standards for looping mains, water circulation and heat tracing;
4. the standards for access to and identification of hydrants, valves, cleanouts, etc.;
5. the pressure testing standards: No leakage should be allowed from water or sewer mains; and,
6. the performance standards for materials - their ruggedness, fire ratings, etc.

The ultimate effect of uniform basic standards will be an overall improvement in utilidor designs and eventually a reduction in capital, operation and maintenance costs. The ultimate objective must be to arrive at standards that permit design and specification of utilidor systems in a manner similar to southern buried systems. -- That is with only plan/profile drawings calling up standard off-the-shelf components. The current practice of each designer going back to square one and designing every nut, bolt and pipe saddle must stop. This type of design is a waste of the client's money and it is the type of design work that engineers can do without.

The resulting stick by stick construction is also unnecessarily expensive. It is a waste of valuable construction time in the short northern summer.

An examination of the costs of three utilidors in Inuvik and one in Frobisher Bay show with remarkable consistency that on the average, materials account for about 33% of the cost of utilidor, engineering for about 17% and construction for about 50%. The adoption of design standards for utilidors and the use of standard, perhaps prefabricated

components will serve to substantially cut costs. The engineering and construction costs that account for about 67% of the total can be cut drastically by prefabrication.

Prefabricated Utilidors

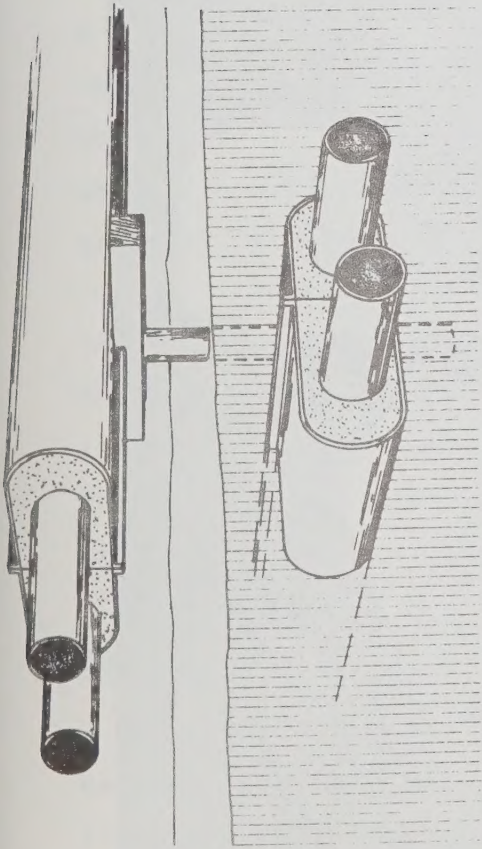
A promising new trend in utilidor design is the recent development of a prefabricated, insulating piping conduits capable of carrying water and sewer mains, as well as heating lines if required. It has metal or fibreglass reinforced plastic exterior with beam strength built into the piping, insulation and casing to provide a self-supporting conduit adaptable to either above or below ground installations. System appurtenances such as hydrants, valves and junction boxes are prefabricated as modules and inserted in the system as required.

This system, known as a U-Dor, was developed and patented by Gamble and Lukomskyj [27]. It is manufactured here in Edmonton by Fiberlite Products Co. Ltd. Figure 6 shows that the U-Dor is longitudinally segmented in standard modules. It bolts together with the standard hydrant modules and service connection modules, etc. inserted where required (Figures 7 and 8).

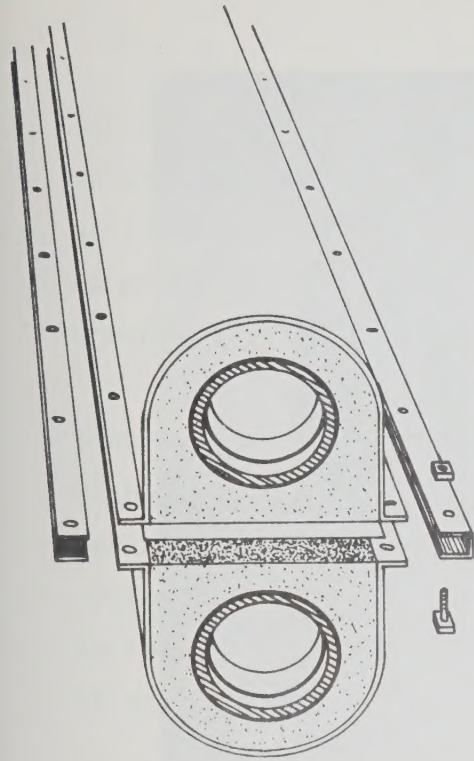
This design approach has many advantages. First, it reduces engineering design time and costs by about two-thirds. In a manner similar to southern buried systems only plan-profile drawings need to be prepared specifying standard components described in the U-Dor manual [28].

Second, the U-Dor reduces on site construction time and costs, which account for about 50% of total utilidor cost, by two thirds or more. The use of skilled labour is also reduced. All components are tested and pre-assembled at the plant before being dismantled and shipped. On site, the modules are linked back up according to a numbering key stencilled onto each part. The U-Dor is also light, making it economical in some cases to fly the entire installation to the site by aircraft. A system could therefore be installed in a few weeks rather than a whole construction season.

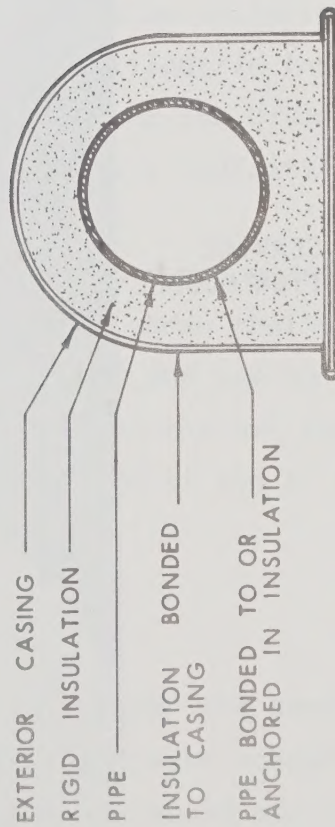
The engineering characteristics of the system are a third advantage. The heat loss from a U-Dor is significantly less than for



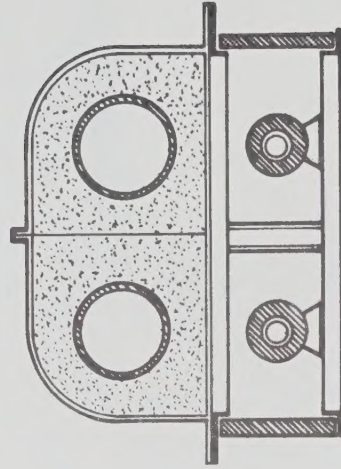
U-DOR SHOWING ABOVE AND
BELOW GROUND INSTALLATIONS



U-DOR ASSEMBLY
WATER & SEWER MAINS



BASIC U-DOR UNIT
WATER SUPPLY & SEWER OUTFALL MAINS



TWO UNIT U-DOR WITH
HEATING PIPE CHAMBER

U - DOR UTILIDOR
(MANUFACTURED BY: FIBERLITE PRODUCTS CO. LTD., EDMONTON)

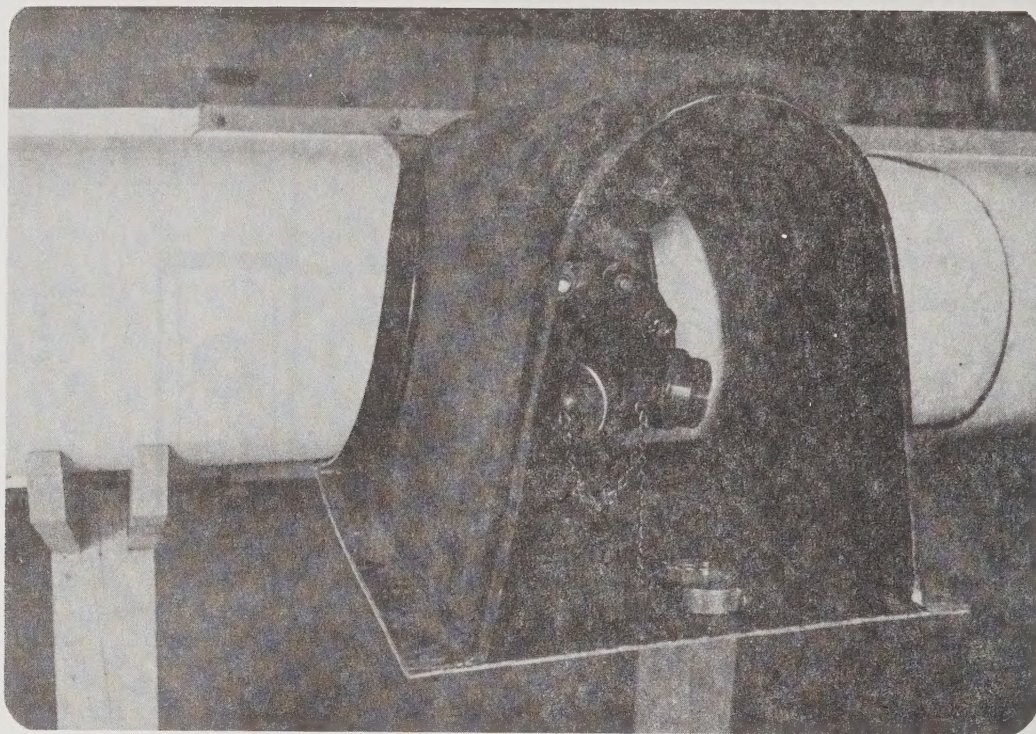


FIGURE 7. U-DOR HYDRANT MODULE

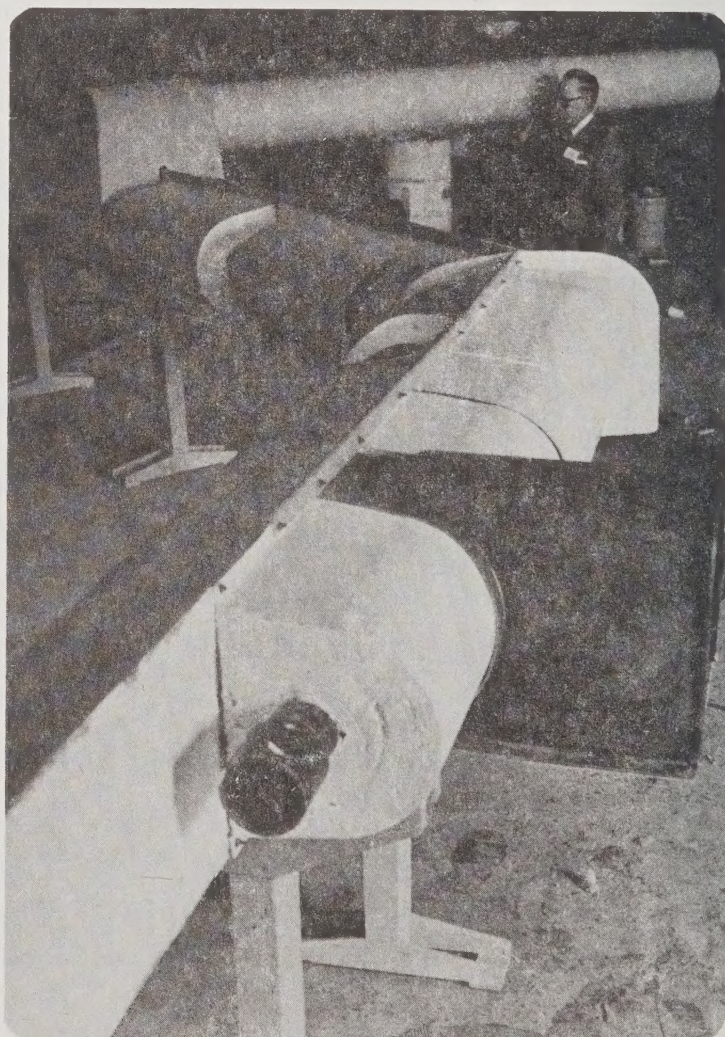


FIGURE 8. U-DOR SERVICE
CONNECTION MODULE

currently common designs. The U-Dor is made of tough high quality materials giving it a life expectancy equal to or in excess of any utilidor now in the north. The structural integrity of the system make it possible to mount it directly on piles caps, run it on stabilized gravel pads, under road fill or even underground.

The fourth advantage is in operation and maintenance. The longitudinally segmented modules can be easily removed for maintenance without affecting any of the other pipes. Damaged areas can be quickly replaced "off-the-shelf" with a similar module. The whole utilidor system can be easily dismantled. This is important in camp installations or in towns that experience unexpected growth requiring larger piping or other changes.

Well, I could go on, but I think that what I've already said is sufficient to illustrate the type of forward progress that can be made in utilidor designs if we make a through analysis of the problem.

I did an analysis of a few moments ago for a hypothetical community of 1,000 household which showed that the Inuvik type 8 utilidor was probably the most economical decision for construction. A similar present value analysis, but this time including a U-Dor design, shows that the U-Dor is cheaper than any utilidor in Inuvik by more than 45%. If one considers capital cost alone the U-Dor is cheaper by about 11% based on 1974 costs. The 1976 costs indicate that the U-Dor capital cost is probably more than 20% less.

Turning now to the new subdivision development proposed for Inuvik that I mentioned previously. It was shown that by optimizing the layout of the roads and utilidors a \$240,000 saving would be realized. If a U-Dor type of utilidor were incorporated the net capital saving over the original proposal would be about \$382,500 or 24% of the total subdivision cost -- a rather significant improvement.

CONCLUSION

I have stressed throughout this paper the need to go back to basics - that we can only achieve better and more economical designs by rigid analysis. As I've described, what we should start to look at are:

1. The overall cost of the poor water and sanitation service now prevalent in northern communities - not just the cost of the hardware but the cost to all parts of government and the community - the resulting health cost, the unemployability cost and the welfare costs, then the social or personal convenience 'costs'.
2. A rigid analysis of design decisions whether it be hauling by truck or a utilidor, a honeybag or a pumpout tank. Most importantly the analysis must include life-cycle-costing (what I've been calling net present value analysis). This will lead to a proper evaluation of alternatives - from hardware components such as the size of household tanks to be provided, to the optimum layout of new subdivisions.
3. The alternative to present standards such as those for fire fighting. This is probably most applicable to small communities.
4. Design standards for utilidors including acceptable materials and performance standards. The ultimate objective must be the standardization of components and prefabrication for off-the-shelf replacement.

Unless we do these things, the cost of basic water and sanitation service to northern communities will continue to be far out of proportion to what is provided. The result, of course, will be that the necessary service will not be provided at all. We as engineers and administrators have a moral obligation to see that this work is done.

Dr. Herbert Schwarz who lives in Tuktoyaktuk captured the mood well in his recently published poem:

A young Eskimo
with good-natured laughter
and joking
carries on his shoulders
piles of garbage bags
from a row
of new council houses
and puts them
on a slow moving truck.

To him the whole thing is ludicrous
 and patiently
 he endures
 piles of stinking muck
 as what he wants
 is to save enough money
 for a down payment on a kicker
 to go whaling again
 in the sparkling Beaufort Sea.

But, what he does not understand
 is that soon
 whale hunts will be over
 and this stinking garbage truck
 is to stay here forever [29].

As Canadians we have many dreams and plans for what we call our last frontier. But with these development plans goes the responsibility of providing viable living environments for the people who make the North their home. The responsibility is to provide services such as water and sanitation that other Canadians take for granted and to provide those services at a reasonable cost. This is our challenge and that, I hope, is why each of us are here today.

ACKNOWLEDGEMENT

I would like to thank Mr. Paul Lukomskyj for his assistance throughout the preparation of this paper.

REFERENCES

1. Department of Manpower and Immigration, Economic Forecasts Branch, Northwest Territories District, Economic Outlook, Northwest Territories 1974-75, Yellowknife: Manpower and Immigration, 1973.
2. Department of National Health and Welfare, Northern Health Service, Annual Report on Health Conditions in the Northwest Territories, 1966 to 1974 inclusive, Edmonton: Health and Welfare.
3. Director, Statistics and Research Division, Alberta Hospital Services Commission, "Computer Print-Out", Edmonton, April 1974.

4. D.J. Gamble, Wabasca-Desmarais Water and Sanitation Feasibility Study, prepared for Northern Development Group, Government of Alberta Executive Council (Edmonton: Associated Engineering Services Ltd., 1974).
5. Department of Indian and Northern Affairs, Canada's North 1970-80 Ottawa: Indian and Northern Affairs, 1972, p. 10.
6. A.U. White and C. Seviour, Rural Water Supply and Sanitation in Less Developed Countries: a Selected Annotated Bibliography, Institute of Behavioural Science, University of Colorado, Ottawa: International Development Research Center, undated.
7. Government of the Northwest Territories, Department of Local Government, Proposed Water and Sanitation Policy for Communities in the Northwest Territories, Yellowknife: Government of the N.W.T., 1973.
8. Government of the Northwest Territories, Supplementary Information on the Proposed Water and Sanitation Policy for Communities in the Northwest Territories, Yellowknife: Government of the N.W.T., 1974.
9. D.J. Gamble, A Review of the Proposed Water and Sanitation Policy with Recommendations on Implementation, prepared for the Government of the Northwest Territories, Edmonton: Associated Engineering Services Ltd., 1973.
10. Associated Engineering Services Ltd., Documentation Report on the Water and Sanitation Policy Computer Program, prepared for the Government of the Northwest Territories, Edmonton: Associated Engineering Services Ltd., 1974.
11. D.J. Gamble and C.T.L. Janssen, "Evaluating Alternative Levels of Water and Sanitation Service for Communities in the Northwest Territories", Canadian Journal of Civil Engineering, Vol. 1, No. 1, 116, 1974.
12. D.J. Gamble and C.T.L. Janssen, "Estimating the Cost of Garbage Collection for Settlements in Northern Regions", Northern Engineer, Winter 1974-75: 32.
13. Wabasca-Desmarais Water and Sanitation Feasibility Study. Ibid [4].

14. Associated Engineering Services Ltd., Documentation Report on the Water and Sanitation Policy Computer Program, Appendix A, prepared for the Government of the Northwest Territories (Edmonton: 1974).
15. A.V. White and C. Seviour, Rural Water Supply and Sanitation in Less-Developed Countries: a selected annotated bibliography. Institute of Behavioral Science, University of Colorado, n.d.
16. John and Irma Honigman, Arctic Townsman Ottawa: Canadian Research Center for Anthropology, 1970.
17. John C. Royle, "Careful Planning Cuts Costs at Fermont", Heavy Construction News, October 15, 1970, p. 26.
18. Personal Communication, F. Rogers, President Rogers and Associates, Edmonton, January 1976.
19. Makale Holloway and Associates Ltd. and Associated Engineering Services Ltd., Aklavik Development Plan, Parts I and II, Planning and Engineering, April 1975, prepared for the Government of the Northwest Territories, Department of Local Government. Edmonton: Associated Engineering Services Ltd., 1975.
20. Department of Public Services, Fire Safety Section, Fire Losses in the Northwest Territories, 1970 to 1975 inclusive, Yellowknife: Government of the Northwest Territories.
21. Personal Communication, Fire Safety Section, Department of Public Services, Government of the Northwest Territories, Yellowknife, January 1976.
22. Personal Communication, Deputy Chief, City of Edmonton Fire Department, January 1976.
23. Personal Communication, J.J. Cameron, Consultant, Edmonton, 1976.
24. D.J. Gamble and P. Lukomskyj, "Utilidors in the Canadian North", Canadian Journal of Civil Engineering, Vol. 2, No. 2, 162, 1975
25. A planning period of 40 years is assumed. The comparison is based on 1974 capital costs, including engineering and construction expenditures, and 1974 annual maintenance costs. An inflation factor of 6.5% is assumed for the 40 year period along with a discount rate (opportunity cost) of 9%. See Gamble and Lukomskyj, 1975.

26. Type 2 and type 7 utilidors are not considered applicable because their cost figures are for the installation of one pipe only. The sewer main in the type 2 utilidor was added later and no cost data is available.
27. "Segmented Rigid Insulated Conduit", U.S. Patent #3934615, Canadian patent pending.
28. Fiberlite Products Co. Ltd., Engineering Guide to Prefabricated Utilidors, Edmonton, Fiberlite Products Co. Ltd., 1976.
29. Herbert Schwarz, "The Garbage Man of Tuktoyaktuk", Tuktoyaktuk 2-3 Toronto: M.F. Fehely, 1975, p. 78.

CALCULATION OF HEAT LOSS FROM PIPES

by

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INTRODUCTION

The formulae presented in this paper represent a compendium of simple calculations relating to heat loss from pipes. Most of the results can be found scattered throughout the technical literature on heat flow, but, perhaps, have not been collected together previously for ready reference as has been attempted herein. The work is reproduced essentially in the same form as in an article by Lukomskyj and Thornton (1976) on piping systems, which is in the Permafrost Engineering Manual (in preparation).

STEADY-STATE ANALYSIS

The second order differential equation which describes the conduction of heat, the diffusion equation, succumbs to only a limited number of closed-form solutions, and these generally relate to geometrically simple boundaries and relatively homogenous materials (Carslaw and Jaeger, 1959). However, such solutions are particularly useful since their explicit nature allows for relatively easy numerical computation.

An important group of these closed-form solutions, the time-independent, steady-state solutions, describe the long (strictly infinite) term heat flow in a region with constant boundary conditions. This paper is concerned primarily with the use of some of these results to aid in the design of utility piping systems in permafrost regions.

FORMULAE AND EXAMPLES

Details of simple formulae and computational procedures relating to the thermal design of a variety of utility distribution systems for northern application are collected in condensed form in Figures A, B and C. An attempt has been made to ensure that these figures, with the

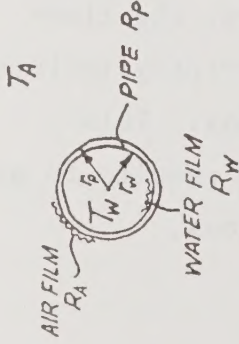
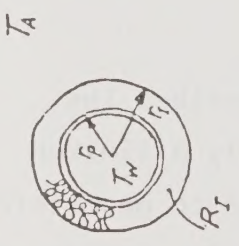
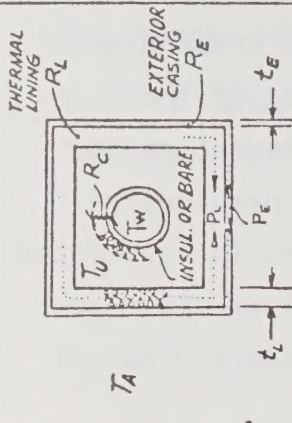
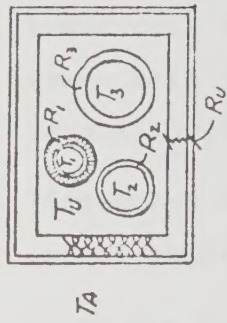
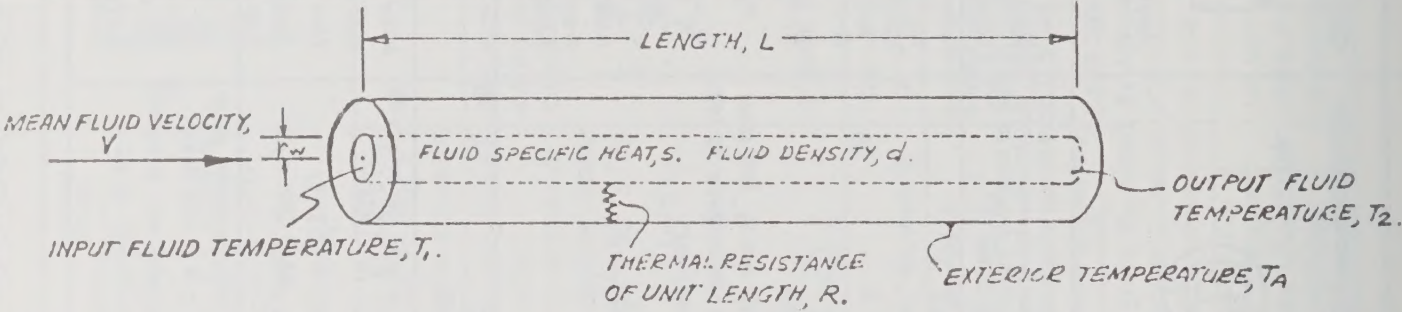
	A1 BARE PIPE	A2 INSULATED PIPE	A3 SINGLE PIPE UTILIDOR	A4 MULTIPLE PIPE UTILIDOR
SKETCH				
ASSUMPTIONS	THIN WALLED PIPE (i.e. $p_p \ll r_p$). R_w IS NEGLIGIBLE. h_a CALCULATION ASSUMES FREE CONVECTION. $R_p < R_a$.	ALL THERMAL RESISTANCES BUT THAT OF THE INSULATION ARE NEGLIGED.	AS A1 OR A2, CONNECTION ENSURES THE TEMPERATURE INSIDE THE UTILIDOR, T_u , IS UNIFORM. UTILIDOR AIR FILMS NEGLIGIBLE.	SAME AS A3.
THERMAL RESISTANCE	$R_p = (r_p - r_w) / (r_p + r_w) \pi K_p$ $h_a = 0.23 \left(\frac{T_w - T_a}{r_p} \right)^{0.25}$ $R_a = 1 / (2 \pi r_p h_a)$ $R_c = R_p + R_a$	$R_c = R_I = \frac{\ln(r_i/r_o)}{2 \pi K_I}$ $\approx \left(\frac{r_i - r_o}{r_i + r_o} \right) / \pi K_I$ if $r_i < 2 r_o$ GIVEN r_i/p_i AND K_I READ OFF R_I FROM FIG. 1.	CALCULATE R_c THE THERMAL RESISTANCE OF THE INTERIOR CONDUIT BY: USING A2 IF INSULATED OR USING A1 IF BARE & REPLACING T_a IN THE FORMULA FOR h_a BY AN ESTIMATE FOR T_u ($\approx T_w$) $R_L = t_L / R_L K_L$ $R_E = t_E / R_E K_E$ $R_U = R_L + R_E$ $R = R_c + R_U$ $T_U = \frac{(T_w/R_c) + (T_a/R_U)}{(1/R_c) + (1/R_U)}$ IF BARE INTERIOR PIPE, ITERATE T_U .	CALCULATE R FOR EACH PIPE AS IN A3 TO GET R_j , ($j = 1, 2, 3, \dots$). CALCULATE R_U AS IN A3 $T_U = \frac{\sum_j (T_j/R_j) + (T_a/R_U)}{\sum_j (1/R_j) + (1/R_U)}$ IF BARE PIPES PRESENT, ITERATE T_U
RATE OF HEAT LOSS	$Q = (T_w - T_a) / R_c$	$Q = (T_w - T_a) / R_I$	$Q = (T_w - T_a) / R$	$Q_j = (T_j - T_u) / R_j$ (PER PIPE) $Q = \sum_j Q_j = (T_u - T_a) / R_U$
INSULATION THICKNESS (GIVEN Q)	N/A	$r_i - r_o = r_o \left\{ \exp \left[\frac{2 \pi K_I (T_w - T_a) Q}{Q} \right] - 1 \right\}$ $\approx \pi K_I (T_w - T_a) Q$ if $r_i < 2 r_o$ GIVEN R_I & K_I , READ OFF r_i/r_o FROM FIG. 1.	OBTAIN R_E AND R_c AS ABOVE $t_L = R_L K_L \left[\frac{Q}{(T_w - T_a)} - R_E - R_c \right]$ IF BARE INTERIOR PIPE, ITERATE T_U , R_E AND HENCE R .	GIVEN ACCEPTABLE Q , CALCULATE R_j AS ABOVE AND EVALUATE $T_u = T_j - R_j Q_j$ FOR EACH PIPE FOR WHICH Q_j IS KNOWN. USING THESE T_u VALUES, FIND CALCULATED Q_j AS ABOVE. USING THESE Q_j AND THE SAME T_u , EVALUATE $t_L = R_L K_L \left[\frac{Q}{(T_u - T_a)} - R_U \right]$ IF BARE PIPES PRESENT, ITERATE T_u AND HENCE T_u .
COMMENTS	OFTEN, FOR METAL PIPES, R_p MAY BE NEGLIGED. IF R_p IS SIGNIFICANT, THE EXPRESSION ABOVE FOR h_a WILL GENERATE AN OVERESTIMATE OF Q . IF $T_a > T_w$ SWITCH T_a AND T_w IN THE EXPRESSION FOR h_a . FORMULAE FOR R_w (AND FOR R_a UNDER FORCED CONVECTION) MAY BE FOUND IN THE CHEMICAL ENGINEERS HANDBOOK, MCGRAW-HILL, 5th ed. SECT. 10.	THE NEGLIGED THERMAL RESISTANCES GIVEN IN A1 MAY BE INCLUDED IF DESIRED.	THE VALUE OF h_a , AND HENCE R_a , IS FAR MORE INSENSITIVE TO THE CHOICE OF T_u AND SO ONE ITERATION ON T_u IS USUALLY SUFFICIENT. OFTEN R_E MAY BE NEGLIGED. SIMILAR CALCULATIONAL PROCEDURE MAY BE PERFORMED FOR UTILIDORS OF DIFFERENT CROSS-SECTION.	IF IT IS CLEAR THAT ONE PIPE DOMINATES THE HEAT LOSS PROBLEM, A3 MAY BE USED TO ESTIMATE T_u . IT IS WISE TO CONSIDER THE HEAT LOSS FROM THE VARIOUS PIPES IF CERTAIN OTHER PIPES CEASE TO FUNCTION.

FIGURE A. ABOVE SURFACE PIPES

TEMPERATURE DROP IN A FLUID FLOWING THROUGH A PIPE	FREEZE-UP TIME FOR A FULL PIPE UNDER NO-FLOW CONDITIONS ($V=0$)
 MEAN FLUID VELOCITY, V LENGTH, L INPUT FLUID TEMPERATURE, T_1 FLUID SPECIFIC HEAT, S. FLUID DENSITY, d. OUTPUT FLUID TEMPERATURE, T_2. THERMAL RESISTANCE OF UNIT LENGTH, R. EXTERIOR TEMPERATURE, T_A	
<u>CALCULATE T_2, GIVEN R:</u> $D = \pi r_w^2 V S R d$ $T_2 = T_A + (T_1 - T_A) \exp(-L/D)$ $\approx T_1 - (T_1 - T_A) L/D, \quad \text{if } L/D < 0.1$ <u>CALCULATE R, GIVEN T_2:</u> $R = L / \pi r_w^2 S d \ln \left(\frac{T_1 - T_A}{T_1 - T_2} \right)$ $\approx L (T_1 - T_A) / \pi r_w^2 V S d (T_1 - T_2), \quad \text{if } L/D < 0.1$	<u>FREEZE-UP TIMES, GIVEN R:</u> DESIGN TIME = $\pi r_w^2 R S d (T_1 - T_0) / (T_1 - T_A)$ (TIME FOR THE FLUID TO DROP TO THE FREEZING POINT) SAFETY FACTOR TIME = $\pi r_w^2 R L d / (T_0 - T_A)$ (TIME FOR THE FLUID AT FREEZING POINT TO FREEZE) <u>CALCULATE R, GIVEN A NO-FLOW DESIGN TIME</u> $R = \frac{\text{time} (T_1 - T_A)}{\pi r_w^2 S d (T_1 - T_0)} \quad (\text{DESIGN CHOICE})$ $R = \frac{\text{time}}{\pi r_w^2 d} \left[\frac{L}{T_0 - T_A} + \frac{S (T_1 - T_0)}{T_1 - T_A} \right]^{-1} \quad (\text{MINIMUM } R)$
COMMENTS: THE SKETCH ABOVE IS SCHEMATIC, AND R AND T_A APPEARING IN THESE EQUATIONS MAY BE REPLACED BY THE THERMAL RESISTANCES AND CORRESPONDING EXTERIOR TEMPERATURES FOR THE CONFIGURATIONS SHOWN IN FIGURES A OR B.	

⊗ ILLUSTRATED IN NUMERICAL EXAMPLES, FIG. 9.

FIGURE C. TEMPERATURE DROP AND FREEZE-UP TIME IN PIPES

associated glossary of symbols in Tables 1 and 2, are essentially self-contained and largely self-explanatory. Hopefully, after some preliminary familiarization, the figures will prove a convenient source of reference to engineers involved in northern pipeline design. For convenience, Table 3 presents some thermal conductivities of common materials involved in such design. Figure A deals with, in turn, heat flow from a bare pipe, an insulated pipe, a single pipe utilidor and a utilidor carrying multiple pipes. In each case, some of the major approximations, in addition to the implied time-independent steady-state assumption, are indicated, with also the inclusion of some comments intended to facilitate an application of the formulae. Expressions giving relevant thermal resistance, rates of heat flow and insulation thicknesses, where applicable, are presented.

Figure B gives similar information pertaining to uninsulated and insulated buried pipes. For each of these two cases, the presence of thawed ground around the pipe is considered, and formulae are included which indicate the dimensions of the resulting thaw cylinder.

Formulae for estimating the temperature drop (or gain) along a pipeline system, and simple expressions relating to freeze-up times under no-flow conditions, are given in Figure C.

To ease the process of computation, numerical values for certain variables in some of the calculations may be read directly from Figures 1, 2, and 3. These curves summarize, respectively, information pertaining to the thermal resistance of a hollow cylinder (insulation shell or pipe), the thermal resistance of a soil mass covering a pipe, and the physical dimensions of a thaw cylinder around a pipe buried in permafrost.

Finally, numerical examples are presented in Figures 4-9 to illustrate some of the computational procedures. Asterisks (*) are located in those sections of Figures A, B and C which have been utilized in the numerical examples.

The calculational schemes presented in Figures A, B and C are based upon time-independent solutions to the heat conduction equation. However, the transient temperature variations which occur at the ground surface, although damped with depth, propagate into the soil,

TABLE 1. LIST OF SYMBOLS

$c = \sqrt{H^2 - r^2}$	ft (m)
$d =$	FLUID DENSITY, lb ft ⁻³ (kg m ⁻³)
$D =$	LENGTH SCALING PARAMETER ft(m)
$h =$	THERMAL FILM COEFFICIENT (OR SURFACE CONDUCTANCE) Btu hr ⁻¹ ft ⁻² °F ⁻¹ (W m ⁻² K ⁻¹)
$H =$	DEPTH OF BURY ft (m)
$K =$	THERMAL CONDUCTIVITY Btu hr ⁻¹ ft ⁻¹ °F ⁻¹ (W m ⁻¹ K ⁻¹)
$l =$	LATENT HEAT Btu lb ⁻¹ (J kg ⁻¹)
$L =$	PIPE LENGTH ft (m)
$P =$	MEAN PERIMETER ft (m)
$Q =$	RATE OF HEAT LOSS PER UNIT LONGITUDINAL LENGTH Btu hr ⁻¹ ft ⁻¹ (W ⁻¹ m)
$r =$	RADIUS ft (m)
$R =$	THERMAL RESISTANCE OF UNIT LONGITUDINAL LENGTH Btu ⁻¹ hr ft °F (W m ⁻¹ K)
$S =$	FLUID SPECIFIC HEAT Btu lb ⁻¹ °F ⁻¹ (J kg ⁻¹ K ⁻¹)
$t =$	THICKNESS ft (m)
$T =$	TEMPERATURE °F (K)
$V =$	VELOCITY ft hr ⁻¹ (m s ⁻¹)

TABLE 2. LIST OF SUBSCRIPTS

A	refers to	AIR
C		CONDUIT
E		EXTERIOR CASING OF UTILIDOR
F		FROZEN SOIL
G		GROUND
I		INSULATION AROUND THE PIPE
j	denotes	1, 2, 3,
L	refers to	THERMAL LINING OF UTILIDOR
O		(ZERO) FREEZING POINT OF WATER
p		PIPE
S		SOIL
T		THAWED SOIL
U		UTILIDOR
W		WATER (FLUID) WITHIN THE PIPE
Z		ZONE OF THAW

TABLE 3. THERMAL CONDUCTIVITIES (K)

MATERIAL	Btu· in/ ft ² · hr °F	cal/cm sec. °C x 10 ⁻³	W m ⁻¹ K ⁻¹
Air	0.157	0.054	0.0226
Polyurethane foam (2 lb/ft ³)	0.16	0.055	0.023
Polystyrene foam (1.9 lb /ft ³)	0.24	0.082	0.035
Rock wool, glass wool	0.27	0.093	0.039
Loose new snow	0.58	0.20	0.084
Snow on ground	0.87	0.30	0.125
Drifted and compacted snow	2.32	0.80	0.334
Water	4.10	1.40	0.59
Ice	14.7	5.10	2.12
Dry peat	0.58	0.20	0.084
Frozen peat (20% soil, 80% ice)	11.8	4.10	1.70
Clay (dry, 106 lb/ft ³)	6.25	2.15	0.90
Clay (thawed, saturated, 106 lb/ft ³)	11.4	3.92	1.65
Clay (frozen, saturated, 106 lb/ft ³)	14.5	5.00	2.10
Sand (dry, 130 lb/ft ³)	7.6	2.62	1.10
Sand (thawed, saturated, 130 lb/ft ³)	22.5	7.58	3.25
Sand (frozen, saturated, 130 lb/ft ³)	28.4	9.76	4.25
Fir, Pine (dry)	0.80	0.28	0.115
Maple, Oak (dry)	1.15	0.40	0.166
Insulating concrete	0.75	0.26	0.108
Concrete	12.00	4.20	1.73
Steel	300.	103.	43.3
Cast Iron	350.	120.	50.5
Copper	2616.	895.	377.0

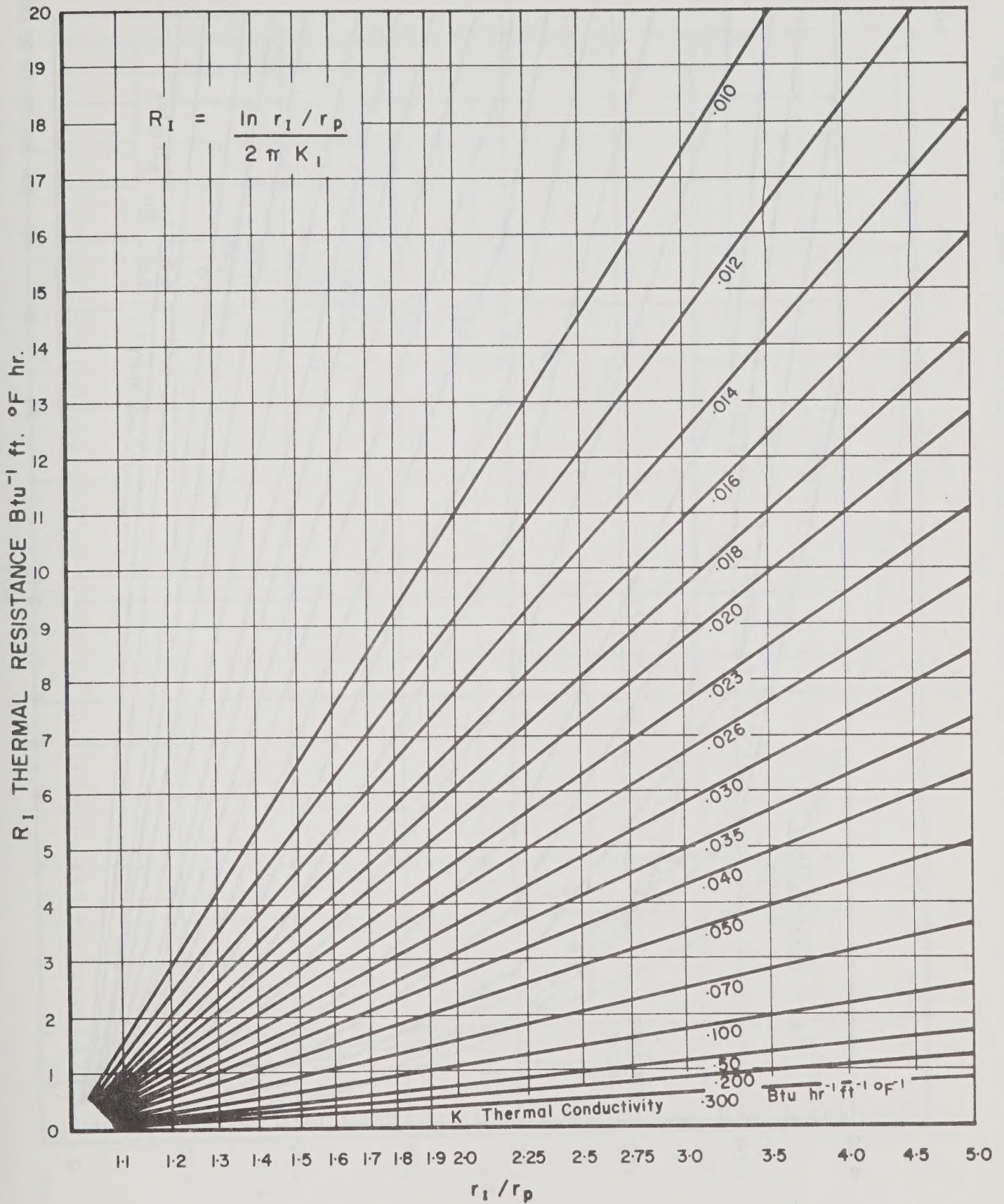


FIGURE 1 THERMAL RESISTANCE OF A HOLLOW CYLINDER

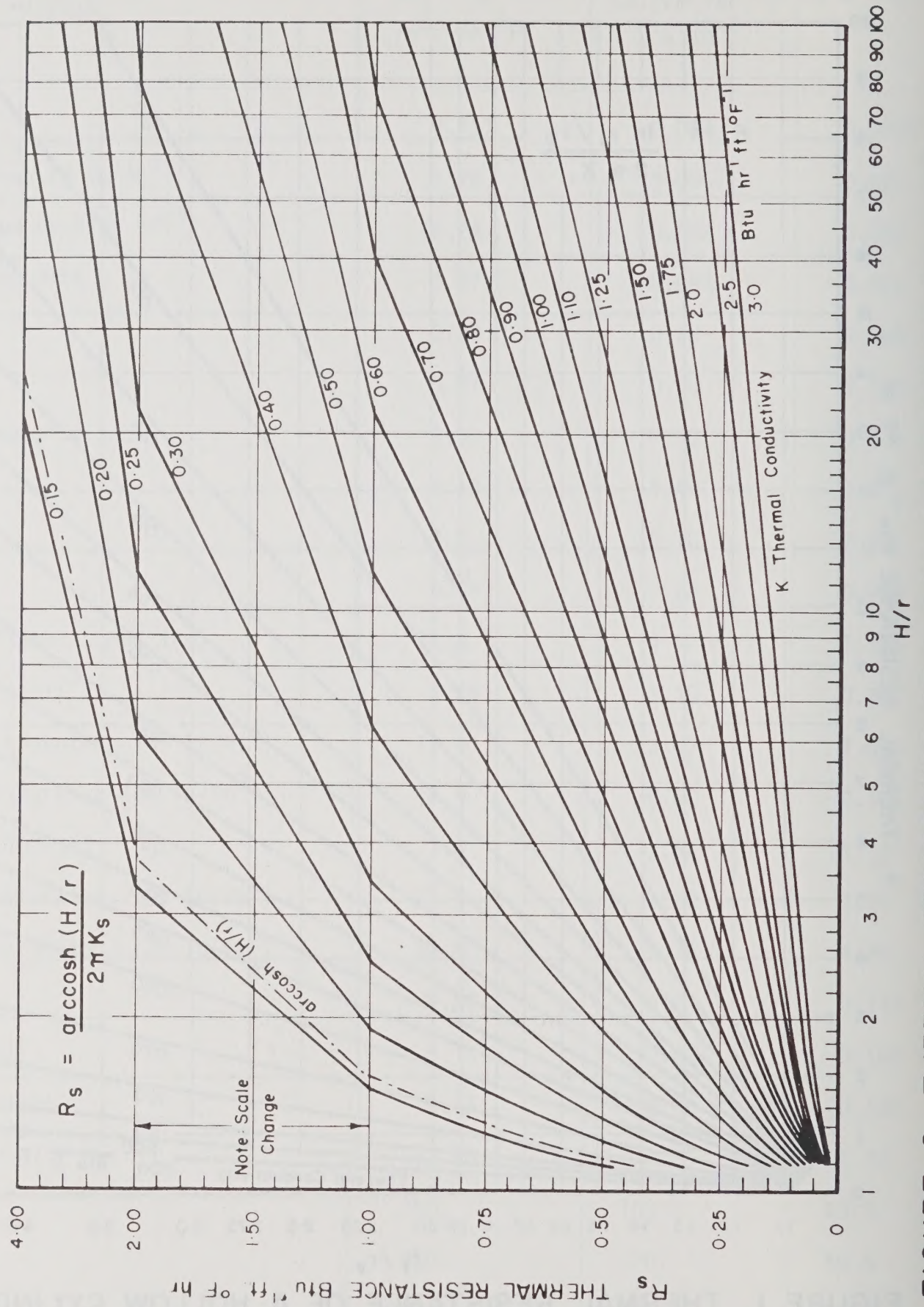


FIGURE 2 THERMAL RESISTANCE OF A SOIL MASS COVERING A PIPE

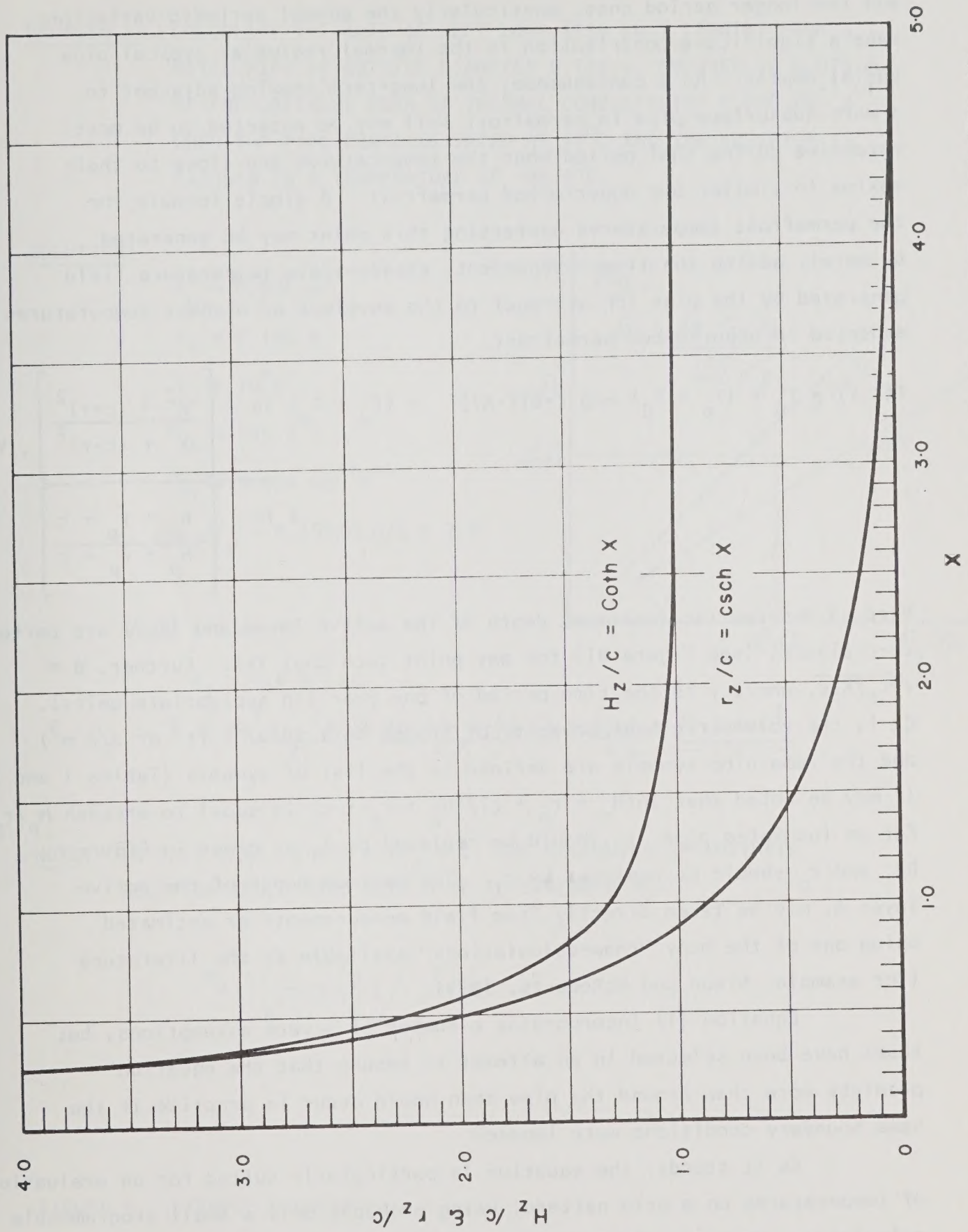


FIGURE 3 DIMENSIONS OF A THAW CYLINDER AROUND A PIPE BURIED IN PERMAFROST

and the longer period ones, particularly the annual periodic variations, make a significant contribution to the thermal regime at typical pipe burial depths. As a consequence, the long-term thawing adjacent to a warm subsurface pipe in permafrost soil may be expected to be most extensive during that period when the temperatures are close to their maxima in similar but unperturbed permafrost. A simple formula for the permafrost temperatures expressing this point may be generated by merely adding the time-independent, steady-state temperature field generated by the pipe (on average) to the envelope of highest temperatures expected in unperturbed permafrost.

$$T(X,Y) = T_G + (T_O - T_G) \exp [-B(Y-A)] + (T_w - T_G) \ln \left[\frac{X^2 + (c+Y)^2}{X^2 + (c-Y)^2} \right], Y > A$$

$$- \frac{2 \ln \left[\frac{H_p + r_p + c}{H_p + r_p - c} \right]}{2}$$

Here, A denotes the (maximum) depth of the active layer and (X,Y) are cartesian co-ordinates (see Figure B1) for any point such that $Y > A$. Further, $B = \sqrt{\pi C_F / K_F y}$, where y is the time period of one year (in appropriate units), C_F is the volumetric heat capacity of frozen soil ($\text{Btu}/^\circ\text{F ft}^3$ or J/K m^3) and the remaining symbols are defined in the list of symbols (Tables 1 and 2). It may be noted that $\ln(H_p + r_p + c)/(H_p + r_p - c)$ is equal to $\text{arccosh } H_p/r_p$. For an insulated pipe, T_w should be replaced by T_i as given in Figure B3, and r_p should be replaced by r_i . The maximum depth of the active layer A, may be taken directly from field measurements or estimated using one of the many "thaw-calculations" available in the literature (for example, Nixon and McRoberts, 1973).

Equation (1) incorporates a number of severe assumptions, but these have been selected in an attempt to ensure that the equation predicts more thaw around the pipe than would occur in practice if the same boundary conditions were imposed.

As it stands, the equation is particularly suited for an evaluation of temperatures on a grid pattern, using probably only a small programmable calculator. However, the important temperatures along the axis of symmetry, and particularly those below the pipe, may be evaluated quite quickly even manually, since then $X = 0$ and the equation simplifies considerably.

PROBLEM 1: CALCULATE THE RATE OF HEAT LOSS (PER UNIT LENGTH) FROM A METAL PIPE OF OUTSIDE DIAMETER 0.152 m, ENCASED IN 0.076 m OF POLYURETHANE FOAM OF THERMAL CONDUCTIVITY $0.024 \text{ Wm}^{-1}\text{K}^{-1}$ WHEN THE PIPE CONTAINS WATER AT 10°C AND THE EXTERIOR IS EXPOSED TO A TEMPERATURE OF -45.6°C .

SOLUTION:

$$r_p = 0.076 \text{ m}$$

$$r_I = 0.152 \text{ m}$$

$$T_w = 10^\circ\text{C}$$

$$T_A = -45.6^\circ\text{C}$$

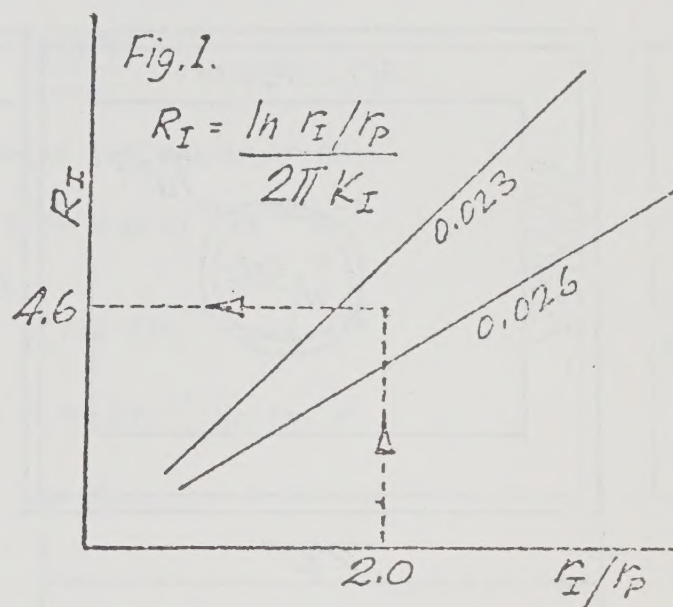
$$K_I = 0.024 \text{ Wm}^{-1}\text{K}^{-1}$$

$$\therefore r_I/r_p = 0.152/0.076 = 2.0$$

FROM FIGURE 1:

$$R_I = 4.6 \text{ W}^{-1}\text{mK}$$

$$\therefore Q = \frac{T_w - T_A}{R_I} = \frac{10.0 - (-45.6)}{4.6} = \frac{55.6}{4.6} = \underline{\underline{12.1 \text{ Wm}^{-1}}}$$

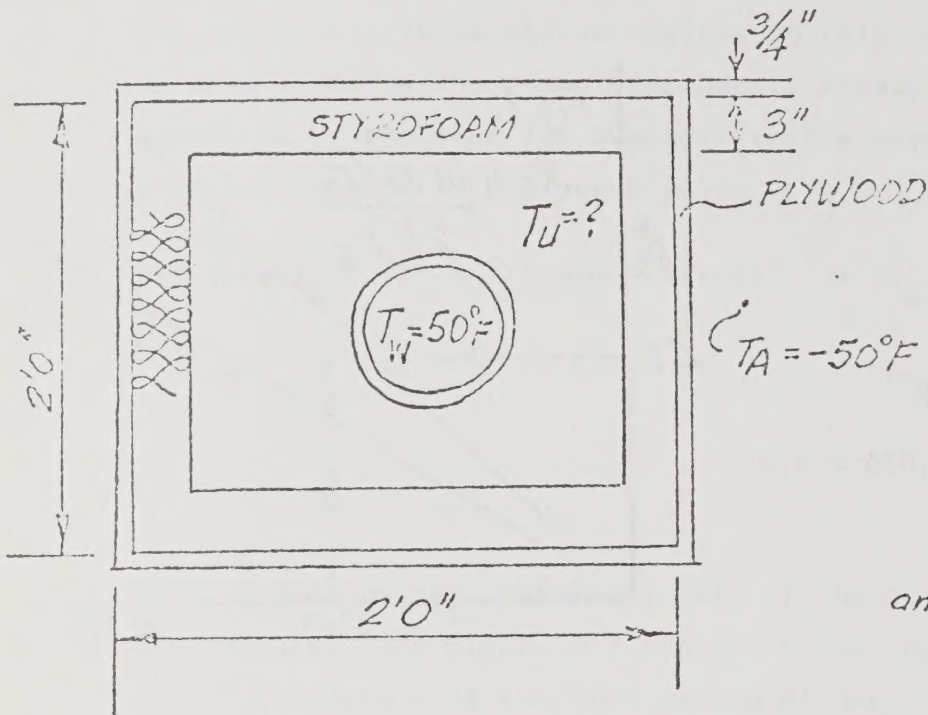


NOTE: IN THIS CASE, SINCE $r_I/r_p = 2$, THE FOLLOWING APPROXIMATE RELATION COULD HAVE BEEN USED TO EVALUATE R_I :

$$R_I = \left(\frac{r_I - r_p}{r_I + r_p} \right) / \pi K_I$$

FIGURE 4. EXAMPLE PROBLEM 1

PROBLEM 2: CALCULATE THE INTERIOR TEMPERATURE AND RATE OF HEAT LOSS (PER UNIT LENGTH) FROM THE PLYWOOD BOX UTILIDOR SKETCHED BELOW WHICH CONTAINS A 6-INCH NOMINAL DIAMETER, CLASS 150 ASBESTOS CEMENT PIPE. TEMPERATURES AND DIMENSIONS ARE SHOWN BELOW.



$$\text{PIPE O.D.} = 7.17''$$

$$\text{I.D.} = 5.85''$$

$$K_p = 0.375 \text{ BTU} \cdot \text{ft}^{-1} \cdot \text{hr}^{-1} \cdot ^\circ\text{F}^{-1}$$

$$K_L = 0.02 \quad \text{---}$$

$$K_E = 0.075 \quad \text{---}$$

$$r_p = 3.58'' = 0.298 \text{ ft}$$

$$r_w = 2.92'' = 0.243 \text{ ft}$$

$$\therefore r_p - r_w = 0.055 \text{ ft}$$

$$\text{and } r_p + r_w = 0.541 \text{ ft}$$

SOLUTION: ASSUME T_u TO BE $+35^\circ\text{F}$ (AN ESTIMATE BETWEEN -50°F AND $+50^\circ\text{F}$)

$$R_p = \frac{0.055}{0.541 \times \pi \times 0.375} = 0.086 \text{ BTU}^{-1} \cdot \text{hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

$$h_A = 0.23 \left(\frac{50 - 35}{0.298} \right)^{0.25} = 0.613 \text{ BTU} \cdot \text{hr}^{-1} \cdot \text{ft}^{-2} \cdot ^\circ\text{F}^{-1}$$

$$\therefore R_A = 1 / (2\pi \times 0.298 \times 0.613) = 0.872 \text{ BTU}^{-1} \cdot \text{hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

$$\text{and } R_C = 0.086 + 0.872 = 0.959 \simeq 0.96 \text{ BTU}^{-1} \cdot \text{hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

$$P_E = 4(2.0 + 0.75/12) = 8.25 \text{ ft}$$

$$\therefore R_E = 8.25 \times 0.075 \times 0.75/12 = 0.101 \text{ BTU}^{-1} \cdot \text{hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

FIGURE 5. EXAMPLE PROBLEM 2

PROBLEM 2 (CONT'D):

$$P_L = 4(2.0 - 3/12) = 7.0 \text{ ft}$$

$$\therefore R_L = 7.0 \times 0.02 \times 3/12 = 1.786 \text{ BTU}^{-1} \text{ hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

$$\therefore R_u = 0.101 + 1.786 = 1.887 = 1.89 \text{ BTU}^{-1} \text{ hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

$$T_u = \frac{(50/0.96) - (50/1.89)}{(1/0.96) + (1/1.89)} = \underline{\underline{16.3^\circ\text{F}}}$$

ITERATE (USE THE NEW VALUE OF T_u AND REPEAT THE CALCULATION):

$$h_A = 0.23 \left(\frac{50 - 16.3}{0.298} \right)^{0.25} = 0.75 \text{ BTU} \cdot \text{hr}^{-1} \text{ ft}^{-2} \text{ } ^\circ\text{F}^{-1}$$

$$\therefore R_A = 1/(2\pi \times 0.298 \times 0.75) = 0.712 \text{ BTU}^{-1} \text{ hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

$$\text{and } R_C = 0.086 + 0.712 = 0.798 \simeq 0.80 \text{ BTU}^{-1} \text{ hr} \cdot \text{ft} \cdot ^\circ\text{F}$$

$$T_u = \frac{(50/0.80) - (50/1.89)}{(1/0.80) + (1/1.89)} = 20.3^\circ\text{F}$$

$$\text{HENCE } \underline{\underline{T_u \simeq 20^\circ\text{F}}}$$

(ANOTHER ITERATION GIVES A VALUE OF $T_u = 19.7^\circ\text{F}$)

$$\text{HENCE } Q = \frac{50 - (-50)}{0.80 + 1.89} = 37.2 \simeq \underline{\underline{37 \text{ BTU} \cdot \text{hr}^{-1} \text{ ft}^{-1}}}$$

PROBLEM 3: THE SAME CONFIGURATION AS PROBLEM 2, BUT INCLUDING A 2-INCH O.D. STEAM PIPE ENCASED WITHIN 1-1/2 INCHES OF ASBESTOS FIBRE, OF CONDUCTIVITY $0.03 \text{ BTU} \cdot \text{hr}^{-1} \text{ft}^{-1} \text{ } ^\circ\text{F}^{-1}$.

SOLUTION: AS IN PROBLEM 2, $R_u = 1.89 \text{ BTU}^{-1} \text{hr} \cdot \text{ft} \cdot ^\circ\text{F}$

TO EVALUATE THE THERMAL RESISTANCE OF THE INSULATION ENCASEING THE STEAM PIPE, USE FIGURE 1 WITH $r_i/r_p = 2.5$ AND $K_i = 0.03 \text{ BTU} \cdot \text{hr}^{-1} \text{ft}^{-1} \text{ } ^\circ\text{F}^{-1}$.

THIS GIVES $R_2 = 4.9 \text{ BTU}^{-1} \text{hr} \cdot \text{ft} \cdot ^\circ\text{F}$.

(THE CONTRIBUTIONS FROM THE STEAM PIPE ITSELF AND THE AIR FILM ADJACENT TO THE INSULATION ARE NEGLECTED.)

BEGIN BY AGAIN ASSUMING $T_u = 35^\circ\text{F}$ (SINCE, THEN, PART OF THE CALCULATION HAS ALREADY BEEN COMPLETED IN PROBLEM 2.)

SO $R_1 = 0.96 \text{ BTU}^{-1} \text{hr} \cdot \text{ft} \cdot ^\circ\text{F}$ (FOR THE WATER CONDUIT)

$$\therefore \sum T_j/R_j = 212/4.9 + 50/0.96 = 95.3 \text{ BTU} \cdot \text{hr}^{-1} \cdot \text{ft}^{-1}$$

$$\text{and } \sum 1/R_j = 1/4.9 + 1/0.96 = 1.24 \text{ BTU} \cdot \text{hr}^{-1} \text{ft}^{-1} \text{ } ^\circ\text{F}^{-1}$$

$$\therefore T_u = \frac{95.3 - 50/1.89}{1.24 + 1/1.89} \cong \underline{\underline{39^\circ\text{F}}}$$

(ANOTHER ITERATION GIVES $T_u = 38.4^\circ\text{F}$)

$$\text{FOR THE STEAM PIPE: } Q_1 = \frac{212 - 39}{4.9} = 35.3 \cong \underline{\underline{35 \text{ BTU} \cdot \text{hr}^{-1} \cdot \text{ft}^{-1}}}$$

$$\text{FOR THE WATER PIPE: } Q_2 = \frac{50 - 39}{0.96} = 11.5 \cong \underline{\underline{12 \text{ BTU} \cdot \text{hr}^{-1} \text{ft}^{-1}}}$$

NOTE: IF THE STEAM PIPE CEASES TO FUNCTION, THE RATE OF HEAT LOSS FROM THE WATER PIPE BECOMES THAT CALCULATED IN PROBLEM 2 ($37 \text{ BTU hr}^{-1} \text{ft}^{-1}$).

FIGURE 6. EXAMPLE PROBLEM 3

PROBLEM 4: A COPPER PIPE OF OUTSIDE DIAMETER 5-1/2 INCHES IS BURIED 6 ft BELOW GRADE IN A SOIL OF MEAN SURFACE TEMPERATURE 20°F AND THERMAL CONDUCTIVITY 0.60 AND 1.0 BTU·hr⁻¹ft⁻¹°F⁻¹ WHEN THAWED AND FROZEN, RESPECTIVELY. WHAT IS THE MEAN SIZE OF THE THAWED ZONE AND AVERAGE RATE OF HEAT LOSS IF WATER AT 50°F IS CIRCULATED THROUGH THE PIPE?

SOLUTION: $r_p = 5.5''/2 = 2.75'' = 0.229 \text{ ft}$

THE THERMAL RESISTANCE OF THE PIPE IS NEGLIGIBLE.

$$T_w^I = (0.60/1.0)(50 - 32) + 32 = 42.8$$

$$T = (32-20)/(42.8 - 20) = 0.526$$

$$c = \sqrt{6^2 - 0.229^2} \approx 6 \text{ ft}$$

$$H_p/r_p = 6/0.229 = 26.2$$

GIVEN $H_p/r_p = 26.2$, READ OFF arccosh 26.2 FROM FIGURE 2.

$$\text{arccosh } 26.2 = 4.0$$

$$\therefore X = 0.526 \times 4 = 2.1$$

FROM FIGURE 3, USING $X = 2.1$

$$H_z/c = 1.03$$

$$r_z/c = 0.25$$

$$\therefore H_z = 1.03 \times 6 = 6.18 \text{ ft} \approx \underline{6 \text{ ft } 2 \text{ inches}}$$

$$\text{and } r_z = 0.25 \times 6 = 1.5 \text{ ft} = \underline{1 \text{ ft } 6 \text{ inches}}$$

HENCE, THE THAWED ZONE WILL BE PRESENT WITHIN A CYLINDER PARALLEL TO THE PIPE, OF RADIUS 1-1/2 ft AND WITH ITS AXIS APPROXIMATELY 2 INCHES BELOW THE PIPE AXIS.

FROM FIGURE 2, WITH $H/r (=H_p/r_p) = 26.2$ AND $K_s (=K_F) = 1.0 \text{ BTU hr}^{-1}\text{ft}^{-1}\text{°F}^{-1}$, WE HAVE

$$R'_s = 0.63 \text{ BTU}^{-1}\text{hr}\cdot\text{ft}\cdot\text{°F}$$

$$\text{SO } Q = \frac{42.8 - 20}{0.63} = 36.2 \approx \underline{\underline{36 \text{ BTU}\cdot\text{hr}^{-1}\text{ft}^{-1}}}$$

PROBLEM 5: A METAL PIPE OF EXTERNAL DIAMETER 0.152 m IS BURIED IN PERMAFROST ($K_F = 1.73 \text{ Wm}^{-1}\text{K}^{-1}$) WITH ITS AXIS 1.22 m BELOW THE GROUND SURFACE WHOSE MEAN TEMPERATURE IS -2.5°C . WHAT IS THE MINIMUM THICKNESS OF POLYURETHANE FOAM INSULATION ($K_I = 0.024 \text{ Wm}^{-1}\text{K}^{-1}$) WHICH WILL MAINTAIN THE SOIL IN A FROZEN STATE (ON AVERAGE) IF WATER IS FLOWING THROUGH THE PIPE HAS A MEAN TEMPERATURE OF 7.2°C ? WHAT IS THE AVERAGE RATE OF HEAT LOSS IF THIS INSULATION THICKNESS IS USED?

SOLUTION: TO EVALUATE R_s USE FIGURE 2 WITH $H/r = 1.22/0.076 = 16$ AND $K_s (= K_F) = 1.73 \text{ Wm}^{-1}\text{K}^{-1}$.

$$\text{THEN } R_s = 0.32 \text{ W}^{-1}\text{mK}$$

$$\therefore R'_I = \frac{(7.2 - 0)}{0 - (-2.5)} \times 0.32 = \frac{7.2 \times 0.32}{2.5} = 0.92 \text{ W}^{-1}\text{mK}$$

TO EVALUATE r_I/r_p USE FIGURE 1 WITH $R_I = 0.92 \text{ W}^{-1}\text{mK}$ AND $K_I = 0.024 \text{ Wm}^{-1}\text{K}^{-1}$.

$$\text{THEN } r_I/r_p \simeq 1.15$$

$$\therefore r_I - r_p = (1.15 - 1) \times 0.076 = 0.011\text{m} = \underline{\underline{1.1 \text{ cm}}}$$

$$Q = \frac{7.2 - (-2.5)}{0.92 + 0.32} = \frac{9.7}{1.24} = \underline{\underline{7.8 \text{ Wm}^{-1}}}$$

NOTE 1: TO DESIGN FOR THE WORST CONDITIONS, IN ORDER TO MINIMIZE THE THAW ZONE DURING THE FALL WHEN THE SOIL IS RELATIVELY WARM, THE CALCULATION FOR THE INSULATION THICKNESS SHOULD BE REPEATED USING THE MAXIMUM TEMPERATURE ATTAINED BY THE UNDISTURBED PERMAFROST AT THE DEPTH OF BURY, RATHER THAN THE MEAN SURFACE TEMPERATURE, T_G .

NOTE 2: TO ESTIMATE THE MAXIMUM RATE OF HEAT LOSS, THE CALCULATION SHOULD BE REPEATED USING THE SELECTED THICKNESS ON INSULATION AND THE MINIMUM TEMPERATURE ATTAINED BY THE UNDISTURBED PERMAFROST AT THE DEPTH OF BURY, RATHER THAN THE MEAN SURFACE TEMPERATURE, T_G .

PROBLEM 6: WHAT IS THE DESIGN FREEZE-UP TIME AND SAFETY FACTOR TIME FOR THE UTILIDOR DESIGN AND TEMPERATURES USED IN PROBLEM 2? (FOR WATER $d = 62.4 \text{ lb} \cdot \text{ft}^{-3}$, $S = 1 \text{ BTU} \cdot \text{lb}^{-1} \text{ } ^\circ\text{F}^{-1}$, $L = 144 \text{ BTU} \cdot \text{lb}^{-1}$)

SOLUTION: $R = 0.80 + 1.89 = 2.69 \text{ BTU}^{-1} \text{ hr ft } ^\circ\text{F}$
(PIPE & AIR FILM + UTILIDOR)

$$\begin{aligned} \therefore \text{DESIGN TIME} &= \pi \times (0.243)^2 \times 62.4 \times 2.69 \times 1 \times (50 - 32) / \\ &\quad (50 - [-50]) \\ &= 5.6 \text{ hr} \\ &\approx \underline{\underline{5-1/2 \text{ hr}}} \end{aligned}$$

SAFETY FACTOR TIME

$$\begin{aligned} &= \pi \times (0.243)^2 \times 2.69 \times 62.4 \times 144 / (32 - [-50]) \\ &= 54.7 \text{ hr} \\ &\approx \underline{\underline{55 \text{ hr}}} \end{aligned}$$

FIGURE 9. EXAMPLE PROBLEM 6

Finally, it should be pointed out that boundary temperatures in the field vary continuously with both random and periodic components, and are often a result of very complex heat exchange effects. In addition, the materials encountered in practice frequently represent rather poor approximations to homogenous, isotropic media. Soil, for example, is a complex, multi-phase, highly inhomogenous medium, the behaviour of which is further complicated by the water component which undergoes phase transitions in the temperature regime under discussion. Some of these complexities may be taken into account by using strictly numerical techniques to solve the appropriate differential equations (for a review, see Goodrich, 1973), but even the most sophisticated still incorporate many restrictive approximations. Further, such numerical methods may often only be utilized for design projects of a considerable magnitude, because of the associated high manpower and computing costs.

In summary, the results presented in this paper, essentially based upon time-independent, steady-state solutions to the heat-conduction equation, necessarily imply a severe idealization. Because of this, the numbers which result from calculations using the outlined procedures should be used as a guide to engineering design, rather than as a gospel.

REFERENCES

- Carslaw, H.S. and Jaeger, J.C. (1959) "Conduction of Heat in Solids", Oxford University Press, Second Edition.
- Goodrich, L.E. (1973) "Computer Simulation", Appendix to "Thermal Conditions in Permafrost - A review of North American Literature", by Gold, L.W. and Lachenbruch, A.H. Proceedings of the Second International Conference on Permafrost, North American Contribution.
- Lukomskyj, P. and Thornton, D.E. (1976) "Piping Systems", Permafrost Engineering Manual, National Research Council of Canada, Associate Committee on Geotechnical Research, in preparation.
- Nixon, J.F. and McRoberts, E.C. (1973) "A Study of Some Factors Affecting the Thawing of Frozen Soils", Canadian Geotechnical Journal, Vol. 10, No. 3, pp. 439-452.

BURIED UTILITIES IN PERMAFROST REGIONS

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Edmonton, Alberta

INTRODUCTION

In much of the North, the basic community needs and services are not available. Facilities, including piped water and sewer systems, which in the "South" are standard may be deemed extravagant for these communities. This may be largely attributed to economic situation, lack of stable income and tax base, and the high per capita cost of providing services. Even in the larger resource extraction and government centre communities where a higher standard of municipal facilities is demanded, designs which solve only technical problems may not be socially desirable or acceptable.

There is no doubt that for permanent communities a piped, buried water distribution and sewage collection system is desirable from both a public health and social perspective. Lack of adequate insulation materials, engineering design information, uncertain economics and other factors have contributed to the use of alternative solutions.

This paper reviews the overall planning and technical design requirements to facilitate the installation of buried utility systems in permafrost regions. It is a summary of a literature review report presented to the Faculty of the University of Alaska as partial fulfillment of the Environmental Quality Engineering Masters program (Cameron, 1975A).

COLD REGIONS UTILITY SYSTEMS

The planning and overall design of buried utility systems in permafrost regions will require changes from conventional "southern" systems. Some aspects of systems designed for cold, but not necessarily permafrost, areas will be applicable; however, in many cases innovative alternatives will be necessary.

Planning

The high cost of providing utility systems in the arctic and subarctic communities makes this the dominant factor in planning, after the functional intent of the community is satisfied (Reed, 1967). Unless the community is appropriately planned and regulated from the outset, any future piped utility systems will be impractical or very expensive. Therefore, long range planning in developing communities should be compatible with future piped systems (Grainge, 1968).

Some compromise with individual desires may be necessary. However, Grainge and Shaw (1971) have shown how, through proper design and planning, multi-family buildings have been acceptable to the indigenous people of Greenland. Compact town designs such as Fermont in northern Quebec have drastically reduced the length of rights-of-way, thereby cutting the utility costs (Royle, 1970). In the north, where the per foot cost of utilities may be ten times that of roads, southern community planning based on vehicular traffic is unrealistic. Gamble (1976) has shown how a subdivision plan cognisant of northern utility system engineering and costs reduced the capital expenditure by 15% over a conventional layout.

Water Distribution Systems

Non-piped

In all but the smallest communities or transient camps there will be some kind of organized water distribution system. Water points within the community have been shown to reduce morbidity rates from enteric and other water-borne diseases; however, disease levels are reduced considerably more if the water is safely distributed to the individual house (U.S. Public Health Service, 1958).

Vehicles may be used to distribute water (Cadario and Heinke, 1972) to buildings with storage tanks located within them. Where facilities to utilize water are not available in the houses, the consumption of water is very low, often less than two gallons per capita per day. In such cases a truck system is generally the most economic distribution system. Although water should certainly not be wasted, this low consumption figure is not conducive to good health or community

growth. In any industrial development this would not be tolerated (Lawrence, 1970). The consumption level at which a truck system becomes uneconomic can be calculated (Associated Engineering Services Ltd., 1972A); however, the low reliability, high risk of contamination and other factors must be considered. As a consequence of these factors the policy of the Government of the Northwest Territories (1973) is to provide piped systems in communities with population of more than 700 persons. In many situations piped systems will be the overall more economic system for much smaller populations.

Piped

There are numerous reports summarizing water distribution systems applicable for cold regions (e.g. Alter, 1969A&B; Murphy and Hartman, 1969; Lukomskyj and Thornton, 1975). These include modified conventional (with insulation and heat added), recirculating (to distribute heat), and intermittent systems (to remove freezable fluid). All of these are applicable to buried utilities in permafrost regions. The single main recirculating system is the most widely used while intermittent pumping has advantages for reservoir filling (Foster, 1974). Conventional non-recirculating systems are possible where the rate of heat loss can be reduced by burial and insulation and where electric heat tracing ensures freeze protection when there is no flow. Service connections may also be recirculating, utilizing a pitorifice or individual household pumps, or modified conventional.

Sewage Collection Systems

Non-piped

The inconvenience and potential health hazards of non-piped sewage systems are greater than for similar water delivery systems. Household modifications to reduce unnecessary water consumption, particularly alternatives to the conventional five gallon flush toilet, and certain in-house treatment methods are applicable in the north (Deans and Heinke, 1972; Rybczynski and Ortega, 1973). Non-water using toilets, such as the composting units (Orr and Smith, 1976), are receiving justified attention; however, the grey water must still be handled. Water saving

systems will decrease the volume of effluent, thereby enhancing the economics of truck collection, however, the same disadvantages as with trucked water distribution apply.

Piped

Conventional sewage collection is by gravity systems. Insulation and in some cases heat input is required to adapt these to cold regions. Intermittent discharge of otherwise trickle flows may be required to prevent icing up of the pipes. Bleeding may provide circulation in the water main and heat input into the sewer system; however, the high cost of procuring, treating and distributing water and particularly the treatment of the dilute sewage discourage this practice except on an emergency basis.

Pressure (Carcich, et al, 1972; Ryan and Rogness, 1976) and vacuum (Averill and Heinke, 1973; Ryan and Rogness, 1976) systems may be installed relatively independent of grade. This allows greater layout flexibility and in some cases higher land use. In permafrost areas deep cuts, which are costly and in some cases impractical, can be avoided. A relatively constant depth of bury, which may be important in thermal considerations, can be achieved and reverse grades caused by differential pipe settlement can be tolerated to a certain extent. Recirculation of a pressure system is impractical and vacuum systems do not drain completely, therefore they must be freeze protected. Both utilize small diameter piping (1.5 to 3-inch) which reduces material and installation costs as well as heat loss. Vacuum toilets require only one litre of water per flush. This will be advantageous in communities with high water costs and may also reduce sewage treatment costs (Jespersen, 1973). All mechanical equipment is prone to failure and this must be considered; however, non-gravity systems have many advantages for buried utilities in permafrost regions and will undoubtedly find application on a limited or community wide basis.

Utilidors

In themselves, utilidors are not water distribution or sewage collection systems but rather multi-pipe housings. They may contain water, sewer and heat distribution piping as well as other conduits.

Their primary function is to consolidate piping, which is relatively more important for above ground systems. Of secondary importance are the thermal considerations (Tobiasson, 1971).

Inuvik, N.W.T. is the classic example of above ground utilidors. Gamble and Lukomskyj (1975) have reviewed the various designs and their components and made an economic analysis including capital and operating costs over their respective life expectancies. Below ground utilidors have been constructed, primarily in Russia. Because of water and soil infiltration, generally below ground utilidors must have no voids and utilize hydrophobic insulation. Other problems and solutions are discussed later.

Above vs Below Ground

In permafrost regions above ground piping has been generally used, perhaps primarily due to early failures in permafrost construction and lack of a hydrophobic insulation. They are however expedient to construct with local labour and minimal equipment. Easy access is provided for maintenance and repair or replacement of piping, insulation, supports, etc. Pipe thawing is facilitated and leaks are easily detected. The foundation design is conventional, for permafrost regions. There is little thermal influence on the ground and other normal activities will have little effect on the foundation stability.

On the other hand there are serious disadvantages to above ground utilities and many advantages to placing them at or below ground level. Above ground piping greatly restricts the movement of pedestrians and vehicular traffic. They tend to unnaturally segment the community, and dictate many aspects of community layout and function. Land use on micro and macro levels is restricted. This is particularly true in the case of service lines that connect each building with the main lines thereby cutting up each lot. The waste space under and near above ground utilidors can not be used and tends to collect refuse and may become a drainage path. Elevated utilidor systems require that buildings be constructed unnaturally high to provide gravity drainage.

Above ground utilidors require expensive overpasses for vehicular and pedestrian traffic. An overpass and underpass constructed in 1974

in Inuvik, N.W.T. cost \$25,000 and \$70,000 respectively (Carefoot, 1975). Thrust blocks at deflections and special anchors for valves, hydrants, etc., are also very expensive, accounting for approximately 30% of the total cost of a two pipe wooden box above ground utilidor constructed in a subdivision of Inuvik in 1972. These very high cost items are often not reported as part of the overall cost per foot. Although their frequency may be reduced by good planning, many will inevitably be required. For buried utilities the cost of these items is greatly reduced and this is, therefore, one of the important economic advantages of burial.

Buried utilities are not subject to vandalism or accidents. They do not require much of the costly maintenance nor have they the short lifespan associated with exposed utilities. Above ground pipes are subject to daily and even hourly temperature fluctuations and must be designed for the minimum air temperature with an appropriate wind velocity. Grainge (1969) reported heat loss from an insulated pipe only one foot below ground level in Inuvik as 43% that of an equivalent above ground pipe. The freeze-up time and risk are appropriately enhanced.

The aesthetic and psychological disadvantages of exposed utilities are also an important consideration. They are often an omnipresent reminder of an already foreign environment and if the exterior is unmaintained they can easily become an eyesore. At best they are generally an unattractive focal point although some effort may be made to camouflage or aesthetically improve them.

The disadvantages of buried utility systems may include difficult and expensive foundation design, particularly in unstable permafrost soils. Repairs will be more costly and time consuming, especially when frozen ground must be excavated. These can be reduced by burial at or near the ground surface or even within embankments.

There are other specific advantages, disadvantages, limitations and restrictions, many of which will be discussed later. Capital and maintenance costs for above and below ground alternatives will vary with the utility requirements, soil and climatic conditions, and project location. Therefore, a general statement can not be made although the economics are briefly looked at later in this paper.

BURIED UTILITY SYSTEMS

In describing the failure of a buried steam pipeline in the permafrost region Zhukov (1958), concluded that this could be attributed to "erroneous attempt to mechanically apply construction experience gained in the central regions of the U.S.S.R. to permafrost regions". Buried utilities in permafrost regions must operate in below freezing temperatures for most or all of the year. Heat losses must be reduced and freezing of the pipes must be prevented. Measures must be taken to prevent ground thawing if ice bearing soils are present below the system and other foundation problems such as frost heaving must also be considered. Materials must be chosen to resist thermal and ground movement stresses and the design must also consider the methods of construction and maintenance of the system. The economics of the system must be analyzed to choose the best materials, configuration and techniques.

Heat Loss

Replacement

Heat may be added to the system at point sources or by continuous electric or pipe heat tracing. Most systems will utilize both methods to varying degrees.

Water may be preheated before it enters the distribution system and at other points as required. Circulation of water is required to distribute heat throughout the system, therefore all the lines must be looped. This may result in considerable extra footage of mains particularly if the area to be serviced was not originally planned on the basis of a recirculating system. Also, the highest water temperatures are at the start of the system where there is continuous high discharge and is therefore least required. The amount of heating input required is determined by the most critical (isolated and coldest) location and the remainder of the system is therefore overheated (Zhukov, 1958).

Heat tracing by pipes containing steam, superheated water, antifreeze solution, etc. may be placed near the water and sewer pipes so that heat is conducted or radiated to them. These pipes are usually placed in utilidors and may be the same pipes used for central heat distribution to buildings. Temperature control with this system is

difficult and overheating of the water pipes may occur. The extra piping required increases the complexity and size of the utilidor as well as the cost.

A variety of constant watt per foot electrical heat tracing systems may be used (Chapman and Holland, 1966). Resistance type cables may be placed inside the pipes for greatest effectiveness (Cheriton, 1966) but present problems at valves and other fittings, therefore, they are more commonly placed on the outside of the pipe. Parallel resistance heating cables (Thermon Canada Ltd., ---) and strips (Chemelex, 1970) contain both conductors and resistance wires in one casing so that they can be conveniently cut to any length. They are thermostatically controlled or self-limiting and have maximum lengths of approximately 600 feet. Induction heating may be used on small metal service pipes (Klassen, 1960) while skin effect current tracing may be advantageous for long supply lines (Pipe Heating Systems Ltd., ---).

Friction losses from water flowing in the pipes will add some heat (Alter, 1969A). This may be important for water supply pipelines (Anonymous, 1966); however, for pipes carrying normal domestic consumption friction heat gains will not be very significant.

Generally heat is not specifically added to sewer lines since they will be warmer than the water that is distributed. When required however, some of the methods mentioned earlier can be applied. Bleeding or warm water injection may be used in some instances.

Reduction

The high cost of energy in the north is common knowledge and measures to reduce heat loss are certainly warranted and in most cases essential. The areas of concern are the total annual and the maximum rate of heat loss. Measures to achieve reductions can be classified as climatic or physical. The former is concerned with the ground temperatures while the latter included modifications to the piping system.

Climatic methods. Periodic surface temperatures are attenuated with depth and this reduction in temperature amplitude is primarily dependent on the thermal diffusivity (thermal inertia) of the soil and the latent heat (moisture content) in the active layer. Since heat loss is directly

proportional to the ground temperature at the level of a pipe, the relative benefits derived from increasing the depth of bury decrease exponentially. Latent heat within the active layer tends to flatten the minimum temperature curve thereby further decreasing the heat loss benefits for pipes located below the depth of maximum thaw penetration. A desirable minimum depth of bury, for thermal considerations, would be the depth at which daily temperature fluctuations are not "felt". For most bare soils, this would be approximately 2 to 3 feet but an insulating snow cover would reduce this.

The annual heat loss is relatively constant for depths below which the ground temperature does not reach the temperature of the fluid being conveyed. Pipes placed any deeper will require heating all year. Shallower pipes will not require heating during the summer (fall) but the low winter temperatures result in a higher annual heating index. If the water is heated when the ground temperatures drop below the freezing point, as is common, this is analogous to stating that there is little benefit in placing the pipes below the active layer. The above considerations have not included the thermal resistance of the soil; however, in the case of insulated pipes, the soil thermal resistance is generally comparatively unimportant. As far as heat loss is concerned therefore, the importance of soil above the pipes is primarily one of reducing the ground temperature amplitude by thermal inertia and latent heat and not providing resistance to heat flow.

The surface conditions determine the relationship between air temperature and ground surface temperature. In the worse case, such as a road surface where there is no vegetation or snow cover, the surface temperature will approximate the air temperature. Compared to a natural ground surface this may easily increase annual heat losses by 25% as well as increasing the maximum rate of heat loss by 40%. The surface conditions are relatively more important for shallow (less than 3 feet) buried pipes (Cameron, 1975B). These factors would indicate that utility lines should be located behind buildings in a utility right of way rather than under or beside roads or cleared surfaces.

Physical methods. The use of insulation is the primary method of reducing heat losses. Only near hydrophobic insulations should be used since it is usually impractical to prevent ground moisture or water from pipe failures from reaching the insulation.

A well insulated pipe will have a low temperature drop along it, thereby reducing the need for high input water temperatures. Insulation is also a better safety factor against freezing than high fluid temperatures. Since heat loss is directly proportional to the temperature of the water, there is a double saving. As pointed out earlier, the method of applying heat at point locations results in fluid temperatures that are excessive at all but the most critical locations, resulting in increased heating cost.

As well as the pipes, all joints and fittings such as valves, hydrants, bends and service connections must be insulated. These areas are usually the most critical but are often neglected; therefore, Lukomskyj and Thornton (1975) recommend the insulation be 1.5 times as thick at these locations. Access manholes should have "frost covers" placed above the pipes (Lawrence, 1969).

Heat losses may be reduced by reducing the piping size. This is more directly applicable to water supply lines since distribution lines are generally sized for minimum fire flow requirements. If acceptable alternative methods of fire protection were available and buffer tanks were placed within each building, water mains larger than 2-inch diameter would seldom be required. Pressure and vacuum sewer systems utilize 1.5 to 3-inch pipe sizes, less than half that required for gravity systems. Also, venting and access manholes are not required as often, or at all, with these systems.

It is general practice to place water and sewer lines within the same utilidor, thereby reducing the need for two structures. Of secondary, but significant, importance is the reduction in heat loss and mutually beneficial heat transfer. Utilidor systems with minimum perimeter have reduced heat loss as well as material requirements. The U-dor (Figure 1) two-pipe system has all voids filled with polyurethane insulation and is encased in a fiberglass structural shell of optimum dimensions resulting in a 20% reduction in heat loss (Gamble and Lukomskyj, 1975; Fiberlite Products Co. Ltd., 1976). These same considerations apply to buried utility systems. At present, the Northwest Territories is thought to be the only jurisdiction in North America permitting water and sewer lines in the same trench. Both must be constructed of approved

pressure pipe with leak tight joints. Similar regulations should be adopted in other areas (Grainge, 1974).

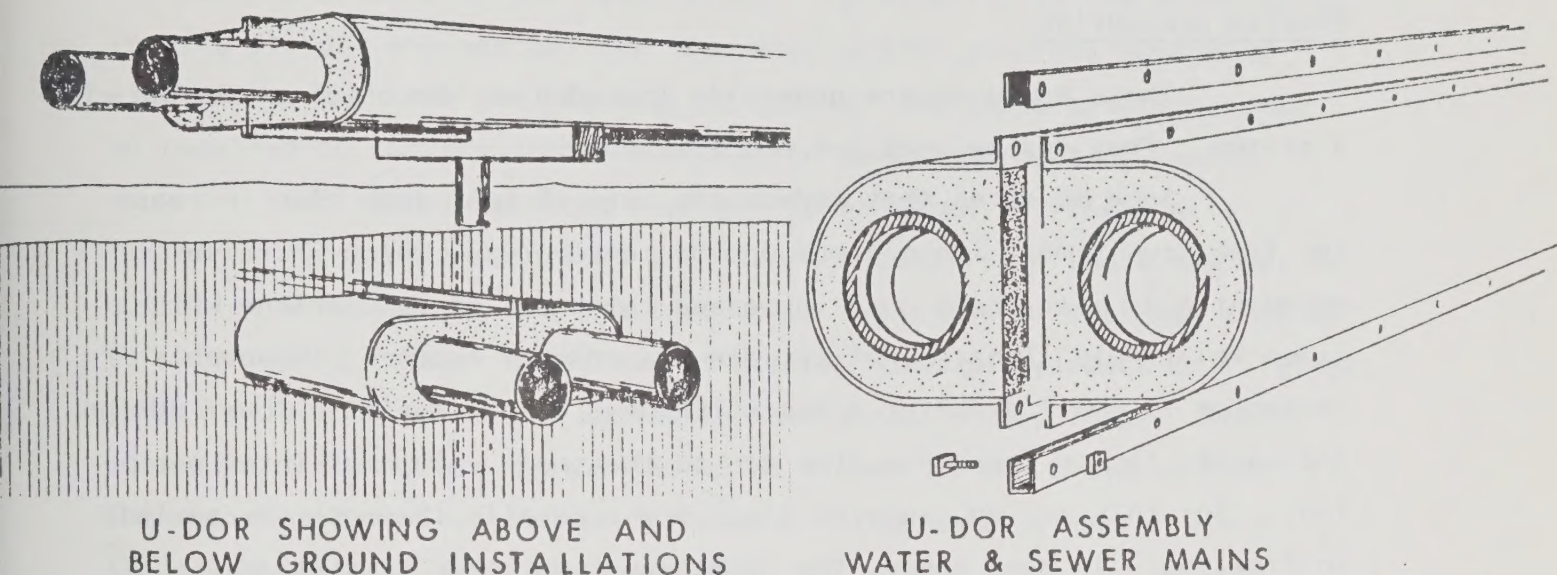


FIGURE 1. U-DOR UTILIDOR
(Fiberlite Products Co. Ltd.
Edmonton, Alberta)

Freezing

Most of the measures that replace and reduce heat losses also, to varying degrees, prevent the freezing of fluid in utility pipes and some may be used to thaw frozen lines. Extra measures and precautions may be designed into the system and the possibility of freezing must be considered.

Although the high latent heat of the water in the pipes provides a considerable heat source, Lukomskyj and Thorton (1975) caution that critical points will freeze long before the entire system, thereby preventing circulation which greatly endangers the system. They recommend that water temperatures should not be allowed to drop below 0.3°C (32.5°F). The design freeze-up time, the time in which an unoperational system commences to freeze, is estimated using the most severe conditions. It should be sufficiently long to permit initiation of remedial measures, allow for minor repairs and/or to drain the system. This will depend on the type of system and the availability of maintenance personnel and

equipment. In smaller communities, the design time may have to be several days, while in larger centres it may be reduced (Lukomskyj and Thorton, 1975).

Passive prevention

These measures are generally included in the original design of a system. They may be used but not altered.

Some measures that reduce the rate of heat loss also increase the freeze-up time. The minimum ground temperature, which increases exponentially with depth, and increased thickness of insulation, which gives relatively linear benefits, are the primary factors. A notable exception is small diameter lines which have a substantially lower design and safety factor freeze-up time due to the small volume of water per foot. For this reason, service lines are generally the most susceptible to freezing. In many cases, the freeze-up time is so short that freezing must be tolerated and thawing designed for.

Generally the greatest danger of freezing is where circulation and/or flow are a minimum, such as at the extreme end of a utility system. Flow in sewer lines may be inadequate, thereby causing icing and eventual freeze-up. If possible, systems should be planned with high demand consumers at these locations.

A thawed zone created around buried utility lines increases the freeze-up time. Many Russian reports have studied this, particularly as it applies to intermittent flowing sewer lines and the initial filling of water lines in winter (e.g. Chernyshoff, 1930; Saltykov, 1944; Kamenskii, 1965 and Konstantinov, 1965). Moist clay of low permeability placed around the pipes provides a heat sink, especially if insulation is placed around the clay (Muller, 1947). Churakov (1959) however, cautions that soil should not be relied on as a safety factor because texture and moisture content vary considerably and also due to the low freezing temperature of moisture in soils, particularly cohesive soils. Generally therefore deliberate thawing of ground to create a large thaw bulb for freeze protection is not recommended and should not be considered in the system design.

Active prevention

In the case of circulation pump failure, heating cables may replace all or most of the heat losses. Conversely, if the electricity is off, standby engines may run the pumps and/or generate emergency electricity for them and the heating cables. Portable generators may be required to service remote circulation pumps and heating cables.

Additional measures may have to be taken if freezing is imminent. Gravity sewer lines will drain naturally so these may not be a problem while vacuum and pressure sewer lines may be designed similar to water mains. Water lines may be drained through hydrants or fittings, judiciously located at low points in the system (Ryan, 1973). Where possible, the complete system should be sloped to one draining facility. Compressed air may be used to force water from small diameter lines (Anderegg, et al, 1960; Grainge, 1969).

Hydrants and similar fittings should be "in-line" (i.e. installed on a tee directly on the main) and pumped out after use, then filled with a nontoxic antifreeze (Lawrence, 1969).

Ground and pipe temperatures in critical areas of a system should be monitored at a central control station (Zhukov, 1958; Anonymous, 1967). When freezing conditions are indicated or predicted, measures can be taken to alleviate the situation and possibly indicate the cause of the problem.

Thawing

The extent to which pipe thawing facilities should be incorporated will depend on the preventative measures incorporated into the design. Manholes provide access to gravity sewer lines so they may be thawed by steam or hot water injection. Water lines may also be thawed in this way if fittings and access are provided. Service lines are often thawed by pumping, hand or electric, warm water through a tube which is pushed into the pipe (P.A.T.---). The pipe and electric heat tracing systems mentioned earlier may also be used to thaw frozen pipes. As well, small diameter metallic pipes may be thawed by running a current through them (Bohlander, 1963; Alter, 1969A). A "thaw wire" greatly facilitates this.

The difficulty in reaching frozen pipes (i.e. trenching frozen ground) makes remote thawing advisable from a time factor and economic point of view. Electric heating cables offer the greatest versatility and are recommended for most situations.

Foundation Considerations

Foundation considerations for buried utilities are generally related to ground stability rather than stress problems. Churakov (1959) states that "soil settlement due to thermal effects is naturally one of the main indices of the practicability of buried (utility) pipelines." In soils that will not settle (or swell) when thawed the problems are greatly simplified. On the other hand, where massive ground ice occurs throughout the route, buried utilities may be impractical. Thaw-settlement may be tolerated or designed for in some instances (Speer *et al*, 1973). Problems, however, may occur at manholes and at service and buildings connections that do not settle equally. Differential settlement may cause undesirable profile changes, including reverse grades, and pipe failures. Adjacent foundations may also be adversely thermally influenced. Moisture from melting ground ice, groundwater and leaks or breaks in the pipeline accumulates in the thawed zone. This may result in water flowing along the pipeline which can cause accelerated thawing and erosion. Large settlements and soil failures can occur in certain soils on relatively flat grades (Lachenbruch, 1970).

Site investigation

A thorough site investigation is necessary to design most facilities in permafrost regions. Many necessary factors can be obtained from permafrost and climatic atlases and numerous reports on specific areas. If sufficient data is not available field investigations and monitoring must be initiated immediately. Although site investigations are very important only a few comments will be made here.

Air temperature information is usually available or can be extrapolated but ground surface and subsurface data may be more elusive. Extrapolation of these from nearby locations should be with caution since surface vegetation, snow cover, soil type and other factors will influence them. Soils, and particularly ice in soils, are generally highly variable

within short distances. The extent of the soils investigation should be consistent with the thermal and structural design calculations in which they will be used. Soils investigation should be carried out at least to the maximum depth of thaw anticipated and deeper in most cases. Pits rather than bore holes are preferred where possible since they indicate in-situ soils, allow visual inspection, and may indicate trenching problems such as water seepage, soil stability and shear strength.

The importance of an early site investigation must be emphasized since design modifications may necessitate further information.

Reduction and prevention of ground thawing

As far as piping is concerned, measures discussed earlier that reduce heat loss also reduce ground thawing. Primarily, these are: reduced size and perimeter of piping configuration and increased thickness of insulation necessary then calculated.

Figure 2 illustrates the use of increased insulation thickness to reduce the thaw depth for the given soil and temperature conditions which are typical of Inuvik. This example indicates the substantial benefits from applying only one inch of insulation and also the impracticality of completely eliminating thawing by the use of insulation alone.

The depth of bury may also be used to alter the thermal influence and hence ground thawing. The example in Figure 3 summarizes the thaw boundary for the given conditions, which were estimated for Frobisher Bay, when the depth of the pipe varies from 3 to 15 feet. The maximum thawing occurs for pipes buried at the depth of the active layer, while pipes which are shallower or deeper result in less thawing. In most installations shallow burial will be the most practical and economic method of reducing ground thawing. Again, it is impractical to eliminate thawing below the normal active layer, however, it can be reduced to easily managed depths.

Water temperatures may be indirectly reduced by increased insulation and continuous electrical heating. Hot wastewater from laundries, certain industrial operations, etc. may have to be cooled by heat exchangers or refrigeration before discharge. The most important period to implement this is during the summer and fall when ground temperatures are at a maximum.

Surface drainage should be directed away from the utility trench and water flow along the trench must be prevented. This may be from

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DO YOU WANT TO INCLUDE THE ACTIVE LAYER ? (YES, NO)
2YESINPUT THE ACTIVE LAYER DEPTH IN INCHES
236INPUT THE SOIL DRY DENSITY IN LBS PER CU FT
2100INPUT THE SOIL WATER CONTENT IN %
225WHAT IS THE PIPE TEMPERATURE
295WHAT IS THE SOIL TEMPERATURE
226WHAT IS THE THAWED SOIL CONDUCTIVITY IN BTU FT
21.0WHAT IS THE FROZEN SOIL CONDUCTIVITY IN BTU FT
21.3INPUT DEPTH OF BURY TO CENTRE OF PIPE IN INCHES
236WHAT IS THE PIPE RADIUS IN INCHES
24WHAT IS THE THICKNESS OF INSULATION IN INCHES
22.0WHAT IS THE INSULATION CONDUCTIVITY IN BTU FT
20.014WHAT IS THE GRID SPACING IN INCHES
26

THE STEADY STATE TEMPERATURE ON THE OUTSIDE SURFACE IS = 27.7907
 THE STEADY STATE THAW RADIUS IS= 1.76009E-2
 THE STEADY STATE THAW DEPTH IS= 35.4965
 THE HEAT LOSS IN BTU PER HR PER FOOT LENGTH IS = 5.90298

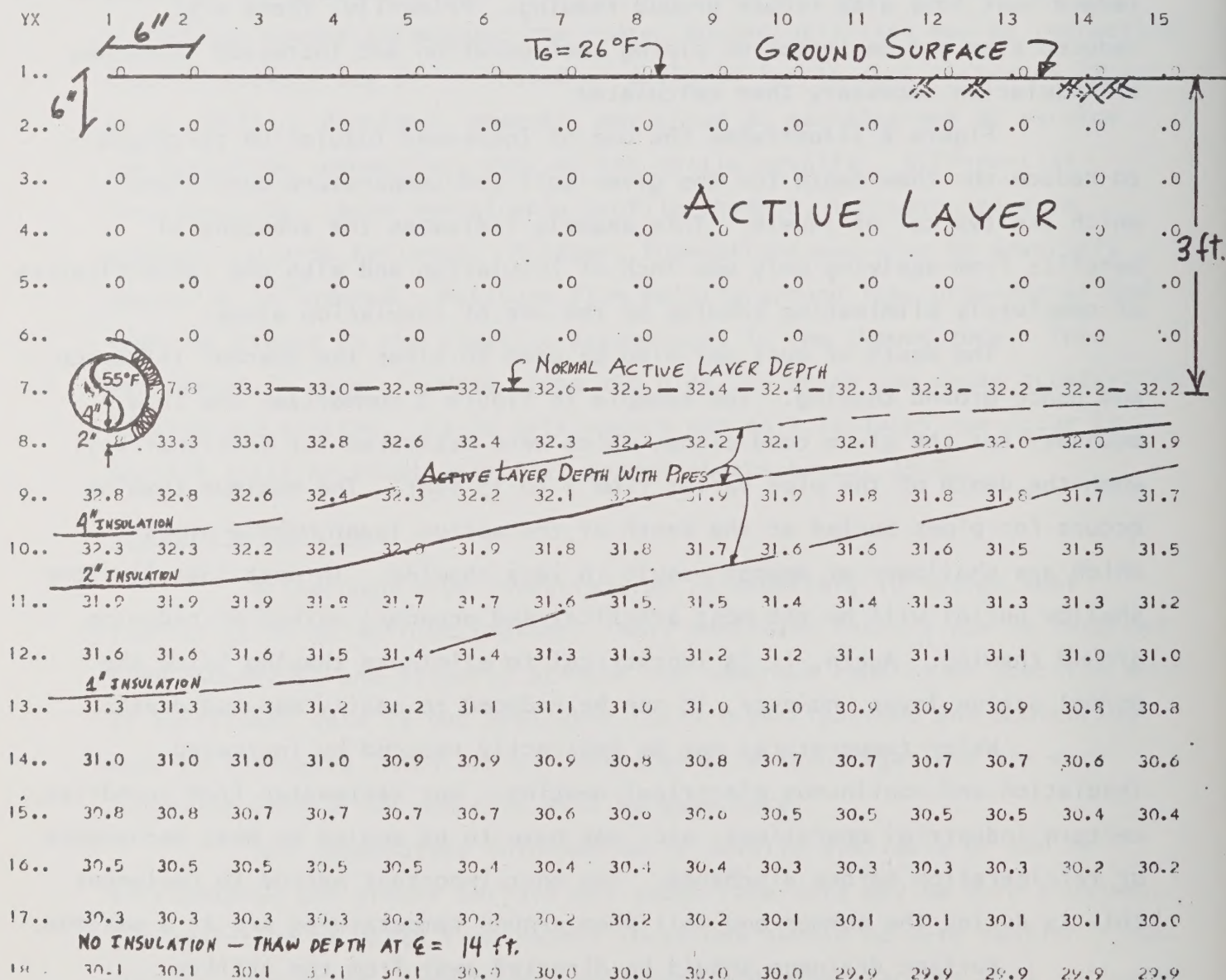


FIGURE 2. EFFECT OF INSULATION ON THAW PERTURBATION

Note: Maximum ground temperatures shown are for 2 inches of insulation case.

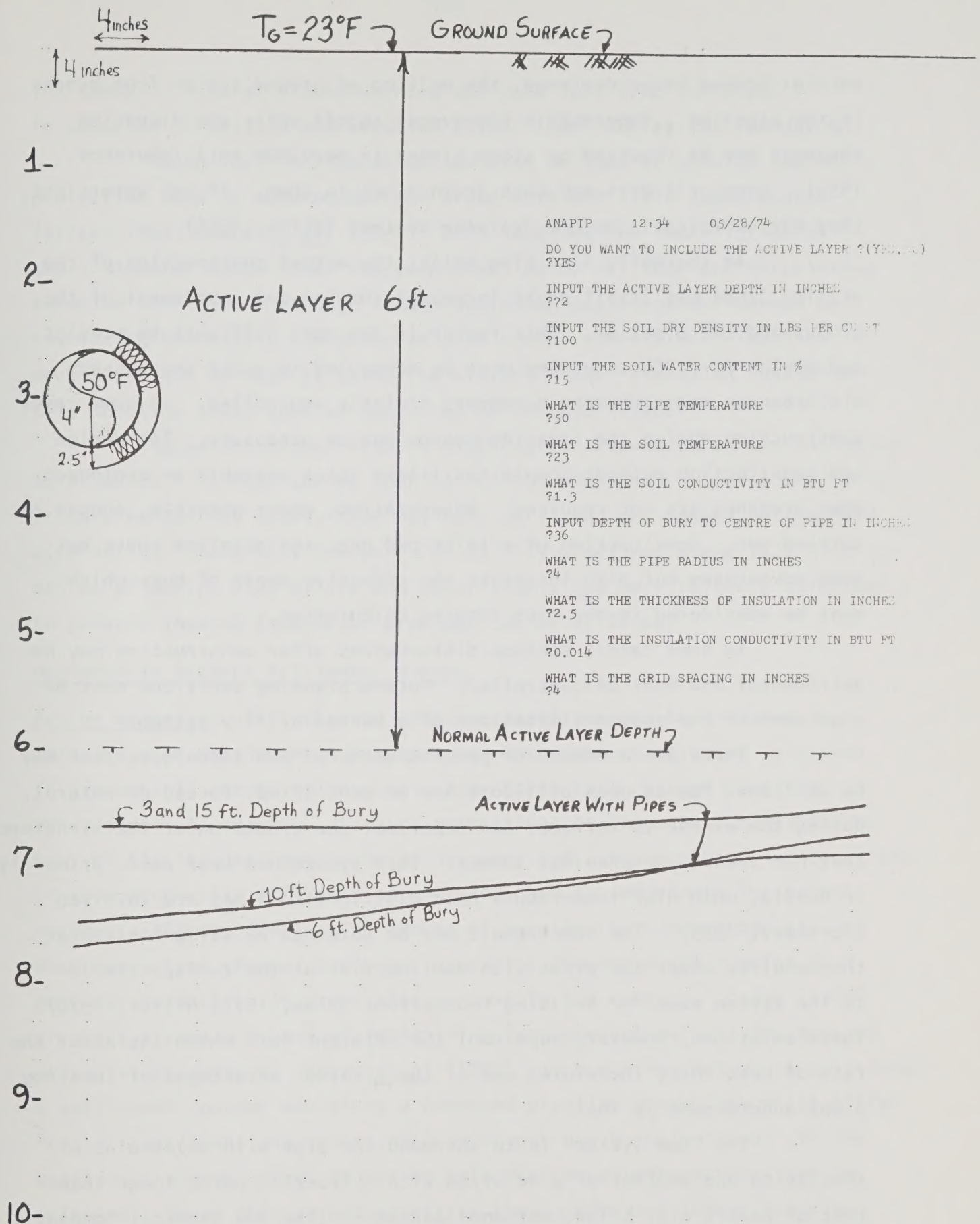


FIGURE 3. EFFECT OF DEPTH OF BURY ON THAW PERTURBATION

Note: Maximum ground temperatures shown are for 3 ft depth of bury case.

natural ground water drainage, the melting of ground ice or from breaks in the pipeline. Impermeable transverse cutoff walls and diversion channels may be required on steep slopes in pervious soil (Churakov, 1959). Open utilidors may have drain lines in them. If not watertight, they may undesirably become drainage systems (Orlov, 1966).

In thermally sensitive soils, the actual construction of the utility lines may itself cause increased thawing and settlement of the ground and the pipeline. This factor is the most difficult to predict and design for. Construction must be scheduled to avoid unnecessary disturbances and equipment movements strictly controlled. In some cases construction during the freezing season may be necessary. The design and construction methods should facilitate quick assembly so prolonged open trenches are not required. Revegetation, where possible, should be carried out. Construction of a thick pad over the pipeline route has some advantages but also increases the effective depth of bury which must be considered in the pipe thawing calculation.

In some cases, surface disturbances after construction may be detrimental and must be controlled. Future planning decisions must be cognizant of the design limitations of a buried utility system.

There are a number of passive measures and techniques that may be utilized. Large open utilidors may be ventilated, forced or natural, during the winter to refreeze and supercool the ground under the structure that had thawed the previous summer. This system has been used, primarily in Russia, when high temperature heat distribution lines are involved (Porkhaev, 1959). The same result may be obtained by using horizontal thermo-piles under the pipes with cooling fins at the surface similar to the system used for building foundations (Rice, 1972; Miller, 1970). These solutions, however, supercool the adjacent soil which increases the rate of heat loss; therefore, one of the greatest advantages of locating pipes underground is lost.

The "Dow System" is to surround the pipe with an annulus of insulation and another of a solution with a freezing point lower than that of water, e.g. brine, methanol and water (The Dow Chemical Company, ---). The solution is cooled and frozen during the winter by the natural ground temperature or by conduction to the surface through special tubes.

The summer's natural ground warming and heat loss from the pipes is absorbed in melting the solution rather than thawing the foundation.

Mechanical refrigeration can also be used to provide thermal protection even in warm permafrost areas with hot fluid temperatures (Giles, 1956; Jahns et al, 1973). This involves the installation of small diameter pipes under the warm pipeline or utilidor and circulating a cooled refrigerant through them. Operating costs may be reduced by insulating the pipes, operating only as ground temperatures indicate necessary, and perhaps by using the winters "cold" stored in insulated salt solution tanks such as described by Johnson (1970).

These techniques require high capital expenditures and increased maintenance. In some cases, such as for hot pipelines or large utilidors in warm permafrost areas, they may have merit and may indeed be the only alternative. Generally however, for utility pipelines there is a high degree of design flexibility and other simple and more reliable solutions to prevent thawing foundation problems can be utilized.

Measures to prevent settlement damage

Active measures. As indicated earlier, pipelines may be designed to tolerate some settlement. Problems may occur when settlement is uneven (differential) resulting in pipe and/or joint failures and possible adverse profile changes. Service connections at the mains and buildings must be flexible and expansion joints provided. Pipes placed in accessible or semi-accessible utilidors may be realigned to compensate for ground movements (Alter, 1969). The amount of expected settlement can be determined from thermal analysis to predict the extent of thawing in conjunction with soils properties, primarily ice content. Crory (1973) presents a simple method of determining settlement from soil dry density and moisture content. Speer et al (1973) use a similar method to calculate a settlement contour map along a proposed pipeline route from which differential settlement and resulting pipe stress can be calculated. If the settlement and/or stress cannot be tolerated an alternate route may be selected. Where this is not practical thaw and/or settlement reducing measures must be included in the design.

In discontinuous permafrost areas, it may be possible and advisable to eliminate that thermal condition (Klassen, 1965; Stanley, 1965). This would probably be carried out throughout a townsite as a general foundation solution for buildings as well as utilities. This solution is most applicable where the permafrost is very thin and is not advisable, without special precautions, in cases where the soil is unstable when thawed. Often this ground thawing may be accomplished simply by stripping off the vegetation cover. This and a number of other natural methods to speed up thawing are discussed by Bakakin and Prokhaev (1959).

In continuous permafrost areas where the permafrost is quite thick the ground may be pre-thawed and consolidated to the maximum depth of anticipated thaw. The thawing methods used may be solar radiation, accelerated natural methods or rapid artificial methods depending on the equipment and time period available. Saltykov and Prokhaev (1959) and the Bureau of Yards and Docks (1955) discuss a number of artificial methods of prethawing and strengthening of thawed soil used as a foundation base.

The more practical method, for most utility pipelines, is to excavate the soil to the maximum thaw depth expected and replace the unstable soil with non-frost susceptible material. Depending on the depth of bury and the time of year this may involve the excavation of frozen ground.

Passive measures. In soils that are unstable when thawed buried utility pipes and utilidors may be supported on piles (Figure 4). The maximum thaw must be calculated and the piles designed to resist frost heaving and prevent settlement. The design of pile foundations in permafrost regions is dealt with in many publications (e.g. Muller, 1947; State Committee of the Council of Ministers for Building Problems, 1964; Sanger, 1969). The pipes or utilidor must be designed with beam strength to span between the piles without foundation support, while subject to the design earth and traffic loads.

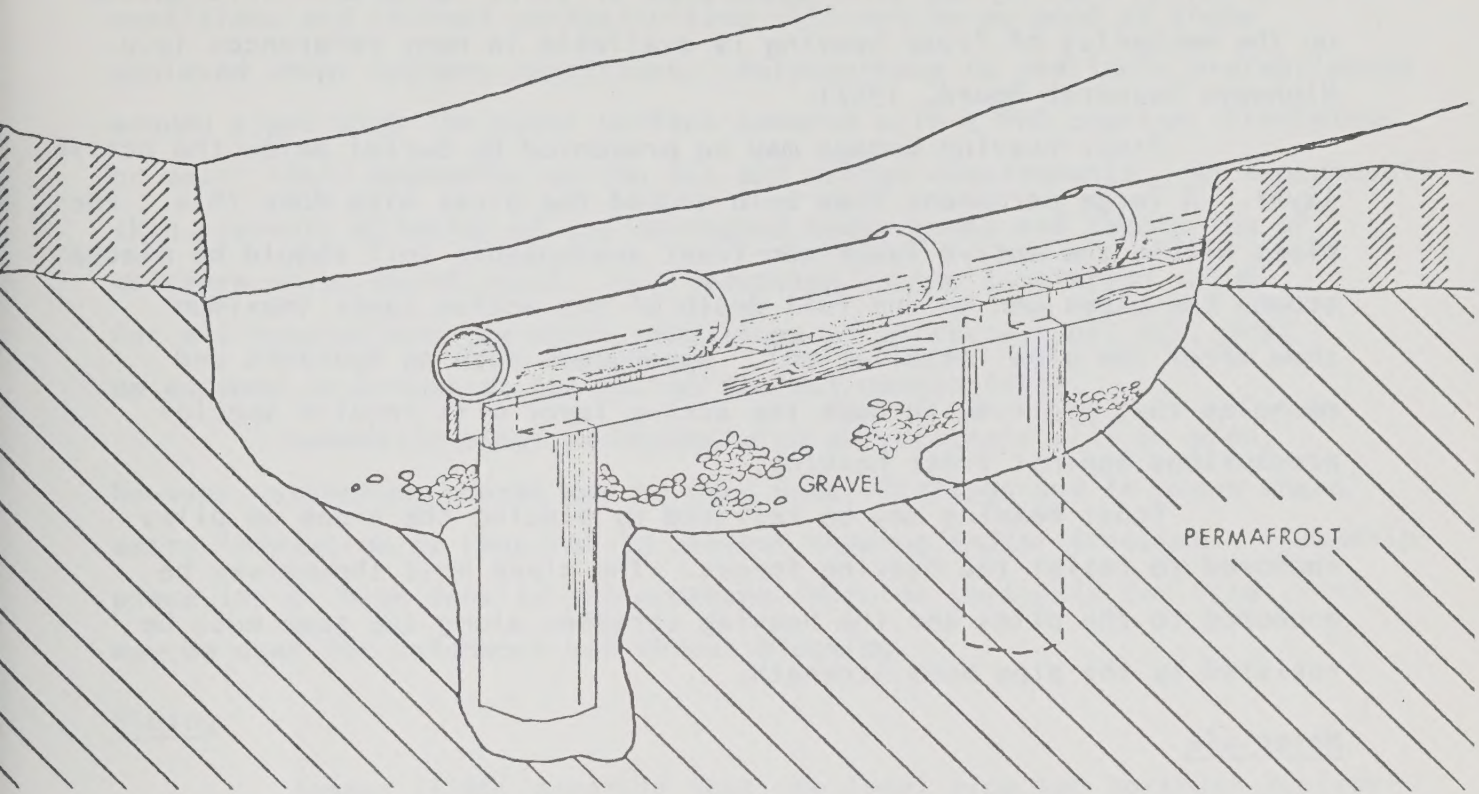


FIGURE 4. SUPPORT FOR SEWER IN PERMAFROST THAT BECOMES UNSTABLE WHEN THAWED. BUREAU OF YARDS AND DOCKS (1955)

Alternatively, lateral beams may be located under the pipes so that their ends extend beyond the thermal influence of the pipe and are anchored in permafrost (Churakov, 1959; J.L. Richards & Associates Ltd., 1974). The installation of such beams would require the excavation of a wide trench or transverse trenches where these beams are desired. This itself may cause detrimental surface and ground thermal influence to such an extent that the benefits are lost.

These designs may be used on selective sections of a system if local soils were found to be such that the overall design being used would not prevent settlement. They may also be used where there is uncertainty as to the nature of the soils and/or the resulting thermal influence of the pipeline construction and installation.

Frost heaving. Generally more consideration is given to thaw-settlement; however frost heaving may be equally damaging. For objects (e.g. pipes) within the soil the heaving tends to be one way and progressive since when the ground thaws the object does not return to the original level.

Differential heaving may also cause pipe or joint failures. Information on the mechanics of frost heaving is available in many references (e.g. Highways Research Board, 1952).

Frost heaving damage may be prevented by burial below the active layer. A large permanent thaw bulb around the pipes also does this. For pipes within the active layer non-frost susceptible soil should be placed around the pipes and to the full depth of the active layer (maximum thaw after the pipe installation). Appendages such as hydrants and manholes that protrude through the active layer will require special precautions against frost heaving.

Frost heaving may be resisted by placing the pipes on piles anchored to resist the heaving forces. The pipes must themselves be anchored to the piles and the heaving stresses along the span must be resisted by the pipe beam strength.

Materials

Insulation

The insulating value of a materials depends primarily on the volume of entrapped gas. If these voids become filled with water the insulating benefits are greatly decreased and when frozen the high thermal conductivity of ice renders the insulation useless. Such is the case when moss and similar materials are used around underground pipes (Copp, et al, 1956). Many older Russian articles have lamented the lack of a hydrophobic insulation (e.g. Churakov, 1959) and this fact has dominated buried utility designs. Lukomskyj and Thorton (1975) state that this is a major reason why above ground utilidors were developed. It is generally impractical to isolate underground insulation from moisture, however, today there are a number of practically hydrophobic insulations which can be used.

Closed cell plastic foams are the most common hydrophobic insulations. Of these extruded and molded polystyrene (commonly called styrofoam and styrospan) and polyurethane are the most used although a few others are available or are being developed (Kritz and Wechsler, 1967). Polyurethane is the more versatile since it can be foamed in place (Anonymous, 1966). However, field application is severely restricted by climatic

conditions and thermal conductivities will not be as good as those achieved under factory conditions. Polyurethane is available prefabricated around pipes with the outer surface covered with a PVC coating, fiberglass or metal shell depending on the use and design requirements. An impermeable skin prevents dilution of the entrapped heavy gases and absorption of moisture which would result in a reduction in the insulation value. For all insulations the worst conditions of moisture, age, etc. must be assumed to arrive at the design thermal conductivity.

Generally pipes prefoamed with polyurethane will be used, however, styrofoam boards may be used under fittings and in areas where extra insulation is required to prevent thawing and/or freezing. Foamed-in-place low or high density polyurethane (Mytolon Chemicals Inc. Ltd.,---) may be used for patchwork and thrust blocking.

Piping

Zenger (1966) proposed that the ideal pipe for northern applications would have "minimum heat conductivity by the wall, minimum thermal expansion coefficient, frost resistance of the material used, convenience to applying thermal insulation, good carrying capacity and low sensitivity to deformation of soil base, resistance to corrosion action by water flowing in it, good transportability, low weight and low cost". Lacking a pipe to meet all these requirements at that time in Russia steel pipe was generally used. There are, however, a number of pipe materials available now that may be better suited for particular conditions. For each project these advantages and disadvantages must be considered and an economic analysis must be made; therefore, only a few comments will be made here.

Where pipe settlement is a possibility, which will be in almost all cases, rigid pipes such as asbestos cement should not be used. Ductile metal pipes offer greater strength but less allowable deflection than plastic pipes, especially if they are lined for corrosion protection. The jointing method used for the pipes should be compatible with the deflections and stresses expected or possible. Smooth joints such as welds would be preferred since they are easier to insulate and pipes may be placed closer together, which is important in utilidors. Fittings and bends should be rigid so that external thrust blocking is not required.

Thermal conductivity of the pipe material is usually not important when pipes are insulated; however, for thick walled plastic, wood and fiberglass pipes, it is an added safety factor. These pipes, however, are more difficult to heat and thaw with exterior heating cables.

Pipes near the surface may undergo large temperature changes, particularly if drained and allowed to cool. Thermal stresses and longitudinal movement may be relieved by the pipe jointing method or expansion joints may be used. Gilpin and Faulkner (1974) found that free-flexing bellows type joints which have no sliding parts performed the best, but even these were only 50% effective when ice coated. Thermal stresses may also be resisted, although this is impractical for pipes with high modulus of elasticity such as metal or some fiberglass pipes. With plastic pipes however, the thermal stress may be only 2% that for steel pipe and can therefore easily be resisted by anchors such as piles or beams, encasing the pipe in a rigid insulation and rigid shell, and/or the soil friction.

The freezing of fluid in a pipe may build up enough hydrostatic pressure to burst it. All pipes are susceptible to a certain extent, but for large diameter pipes, polyethylene appears to be the least vulnerable. For small diameter lines copper and thin walled steel piped have limited freeze-thaw capability.

Ease of pipe installation is a major factor in the selection of pipe and jointing method. Light, ductile fused-joint plastic pipes may be joined and service connections installed, pressure tested, etc. on the surface then lowered into the trench and backfilled as trenching proceeds. This may be important when the trench cannot be left open for long periods.

Construction

Trench excavation and pipe installation may be the highest cost items. Therefore, designs that best facilitate these will be the most economic and in many cases these considerations will dictate the design. Many of the construction problems will be similar to those encountered in other northern projects. These include a shortage of local skilled workers, lack of facilities, scheduling problems due to transportation

and climate, and other factors. Local conditions and the size of the project will play an important role in the design and construction technique.

Construction projects are normally designed and tendered from standard specifications that are primarily concerned with legal considerations, defining responsibilities and describing the finished product. Contractors not intimately familiar with the site conditions and having limited arctic experience may thereby be misled and unknowingly underestimate the difficulty of a project (Associated Engineering Services Ltd., 1972B). This may lead to construction as well as financial disaster. Alternatively, specifications could include adequate site information, and specify construction methods, equipment and scheduling. In many cases it may be more economical to invite tenders on a cost-plus basis and give more consideration to contractors experience and expertise. This is especially useful on projects where there is limited construction experience and a high financial and construction risk.

Seasonal scheduling

The timing of an installation is an important decision that requires a number of trade-offs, many of which will depend on local soil conditions. A number of the important factors and the influence of the seasons on these is presented in Table 1.

It can be seen from this Table that generally the extremes of the summer and winter should be avoided. Most projects are of course of some duration and climatic conditions may not be as predicted. These should be considered in the construction schedule and equipment requirements. The whole project or certain areas or aspects may be staged to take advantage of the seasons.

Excavation

Often the design and/or schedule will necessitate the excavation of frozen soil. Generally the most expedient methods of trenching are blasting and backhoe excavation (McCullough, 1958). Near the surface, ripping may be used (Lange, 1964). These and a number of other techniques are discussed by Zelenin (1959), Dean (1962), and Foster-Miller Associated Inc. (1973). The more sophisticated methods such as laser beam, sonic,

TABLE 1. RELATIVE SEASONAL PROBLEMS FOR INSTALLATION OF BURIED UTILITIES

SEASON FACTOR	WINTER	SPRING (T>0°C)*	SUMMER	FALL (T<0°C)*
Excavation of Frozen Ground	4	3	2	1
Slumping of Thawed Trench Wall	0	2	4	1
Infiltration of Water (Ground and Surface)	0	2	4	2
Frozen Backfill Material	4	3	1	2
Ground Cooling	4	1	0	2
Ground Heating	0	2	4	1
Construction (Men and Equipment)	4	2	1	2
Damage to Surface	1	2	4	2

LEGEND

<u>Code</u>	<u>Description</u>
0	No Problem or Not Applicable
1	Best-Least Problems
4	Worst-Most Problems

* Air Temperature

chemical attack, etc. have limited application while many others are only applicable to large areas or particular soils. Natural thawing has been mentioned earlier and may be applicable in some soils and when there is considerable lead time. Artificial thawing has many of the same limitations and requires specialized equipment although the time factor is considerably reduced.

Trench excavation, with a backhoe or continuous trencher equipped with "frost teeth" (Ewing, 1974) can be accomplished in some materials but most will require blasting to achieve a reasonable trenching rate. Frozen silts and fine sand are more effectively blasted by a "slow" explosive while frozen gravel of high moisture content requires a faster explosion to shatter it (Bureau of Yards and Docks, 1955). Large heavy duty bucket excavators such as used in northern oil pipeline construction can dig through most soils but it is unlikely they will be available for utility pipe excavation. Pneumatic chisels and larger pneumatic hammer attachments for hydraulic backhoes may be useful for small excavations or in tight conditions. Test pits dug for soil samples may be used to try various combinations of excavation techniques.

Maintenance

Any utility system should be designed for minimum maintenance and at the same time allow for regular maintenance. Most of these factors are fairly common waterworks procedures.

The excavation of frozen ground to repair a leak can be very time consuming and require lengthy, inconvenient system shut-down. Backfilled material should not contain stones over four-inch as these are very difficult to excavate when the ground is frozen. A shallow buried system facilitates easy excavation (Underwood McLellan & Associates Ltd., 1974). Some buried utilidor designs have access through the top to facilitate repairs. Others may be very shallow so that the top is used as a sidewalk and provides easy access (Jacobsen, 1973; Durnovo, 1969). These features of course must be weighed against the extra cost in terms of heat loss and the greater possibility of freezing with a shallow buried system. The location of all pipes, valves, etc. must be well documented and a colour coded marker ribbon placed one foot

above them for ease of location and identification. An operator's manual should contain background information on the system, particularly the function and operation of various non-conventional characteristics of the system such as circulation pumps, special hydrants, heating cables, etc. Detailed procedures must be established for such events as a line break, electricity stoppage, prolonged shutdown, cold weather start up, etc.

Water and ground temperature sensing equipment should be installed and monitored. In some cases settlement gauges would be of benefit. Water flow and consumption should be checked and judiciously placed flow meters, or portable meters could isolate leaks. Small leaks are difficult to notice and locate but may cause detrimental thawing if unchecked.

If excess thawing and settlement occur, the cause should be determined and remedial measures must be taken. Sewer and water temperatures should be checked to see if they are too high. In some cases, it may be necessary to excavate the pipe and replace the unstable soil, place extra insulation under the pipes, and/or provide anchorage by piles, transverse or longitudinal beams.

Economics

Project decisions

Estimating costs in the arctic is a formidable task even for those familiar with its characteristics. Above ground utilidors have been more common and costs for these are fairly well documented and are much easier to estimate (e.g. Dawson and Slupsky, 1968; Grainge, 1969; Leitch and Heinke, 1970; Associated Engineering Services Ltd., 1973A; Gamble and Lukomskyj, 1975). There is very little cost data on buried utilities in permafrost regions; however, the capital cost for an underground installation at Inuvik, N.W.T. has been estimated to be \$30 per foot lower than typical above ground costs (Associated Engineering Services Ltd., 1973B). Operation and maintenance savings would be in addition to this. A buried system currently being installed in Frobisher Bay is comparable in cost to an above ground utilidor (James, 1976).

Design decisions

Design decisions are of an individual or overall nature, although few are independent. Table 2 presents the major parameters that are considered in the design and their rate of influence. It shows the synergistic characteristics of various elements. The relative importance of each will depend on their incremental cost. This table shows that there is no simple trade-off even between the two most important variables; insulation thickness and depth of bury. In many cases design criteria such as no thawing or minimum freeze-up time will dominate the calculations and dictate many of the variables. Other factors such as the mean surface temperature may be relatively inflexible.

Individual decisions such as the selection of pipe material to be used may also be interdependent and multi-beneficial. These of course must be evaluated for each case.

All financial decisions must be based on the equivalent cost over the expected life. Gamble and Lukomskyj (1975) point out that the capital cost of a utilidor built to last 50 years is not much greater than one which lasts 15 years, and state that "capital costs can be reduced by lowering standards but the saving is short-term since the owner inevitably pays for the initial savings through high operating and replacement costs".

THERMAL CALCULATIONS

In order to design buried utility systems in permafrost regions a number of heat transfer problems must be defined and adequate solutions made available to engineers. Some of the problems encountered are of such mathematical complexity that exact solutions are not available. However, in many practical problems the limited extent to which the boundary conditions and the physical properties of the materials can be mathematically represented may make the results of precise, complex calculations no more accurate than solutions using well-understood simple approximations. A better understanding and quantification of the thermal problems aids to reduce the uncertainty factor and facilitates solutions through design rather than failure experiences.

TABLE 2. RELATIVE INFLUENCE OF VARIOUS ENVIRONMENTAL CONDITIONS ON BURIED UTILITIES

INFLUENCE CONDITION	Heat Loss		Freeze-up Time	Foundation Thawing	Installation	
	Annual	Maximum Rate			Trenching Cost	Material Handling
Increased Insulation Annulus Area	+L	+L	+L	+E to +S	-S	-S
Increased Depth of Bury	+L to +S*	+E, +E	+E	Varies**	-E	-L
Reduced Pipe Diameter	+L	+L	-L	+L	+S	+L
Reduced Piping Configuration (Perimeter)	+L	+L	+L	+L	+L	+L
Reduced Fluid Temperature	+L	+L	-L	+L	N/A	N/A
Lower Mean Surface Temperature	-L	-L	-L	+E	Varies	Varies

LEGEND

<u>Code</u>	<u>Description</u>	<u>Code</u>	<u>Description</u>
+	Beneficial Effect	0	No influence
-	Detrimental effect	S	Slight influence
N/A	Not applicable	L	Linear influence
		E	Exponential influence

* +L influence to depth of active layer and +S below this

** Maximum for pipes at depth of active layer

Steady State Conditions

These conditions strictly apply only after a long time period has elapsed during which the boundary conditions are unchanged. However, a number of complex situations can be estimated by simple steady state relationships.

Solutions to a number of thermal pipeline problems such as heat loss, time to freeze-up, and minimum flow requirements for bare and insulated pipes are given by Fryer (1970). Lukomskyj and Thornton (1974) and Thornton (1976A) have recently summarized many of the engineering heat transfer problems for above ground pipes and utilidors and below ground pipes. These include the above problems as well as the ground thawing considerations and thaw bulb dimensions for insulated and bare pipes.

The steady state solutions are generally for an infinite homogeneous soil. In many cases there is a surface layer such as gravel embankment, insulation, peat, pavement, etc. that has a substantially different thermal conductivity than the soil. For these cases solutions may be obtained by calculating the thermal equivalent thickness of soils from the ratios of their thermal conductivities. This new effective depth of bury is used in the thermal equations.

Multi-pipe and non-circular utilidors problems may be estimated by using an equivalent cylinder. The radius of this may be that of a circle with equal perimeter or it may be large enough to encompass the extremes of the actual shape. The choice will depend on the geometry of the utilidor and a few estimates may be tried and the most reasonable solution utilized. The thermal resistance of the insulation around the equivalent cylinder should be such that the heat loss is equal to that of the actual utilidor. A simple finite difference computer program developed for buried utilities and other thermal problems (Thornton, 1976B) is useful when there are odd geometric and boundary or internal thermal conditions.

Transient State Conditions

Transient state conditions are the more common and also the most difficult to solve. This category includes time dependent temperatures at boundaries and problems involving changes of state, freezing and

thawing. With respect to buried pipes, calculations of minimum and maximum ground temperatures, the depth of the active layer, heating required, etc. are important problems involving transient ground surface temperatures.

In the simple case of a sinusoidal ground surface temperature attenuated into a dry, homogenous soil, the time dependent as well as minimum and maximum ground temperatures at any depth can be easily calculated (e.g. McKay, 1971; Gold and Lachenbruch, 1973). Other conditions such as layered soil may be included (Lachenbruch, 1959). There is no solution to include the latent heat, which greatly limits these equations. However, the simple case predicts a larger amplitude; therefore, it is useful in some calculations. The equations are also valid below the active layer and are, therefore, useful in estimating thawing resulting from buried pipes.

Depth of active layer

The depth of the active layer is required to estimate the temperature field around pipes. It is the after construction active layer depth that is required, therefore, it must be calculated. The depth of thaw calculation techniques are generally Neumann or Stephan solutions. The former involves the solution of the appropriate transcendental equations given in many references (e.g. Carslaw and Jaeger, 1959) which have been approximated by Aldrich and Paynter (1953, 1966) by the well known modified Berggren equation and more recently have been solved with fewer assumptions by Nixon and McRoberts (1973). Stephan's solution was originally formulated to calculate the depth of ice formation and included only the latent heat of fusion. In the modified Stephan solutions, an estimate of the heat utilized in warming the soil in the permafrost and the active layer during the thawing period is included. Janson (1964, 1968) includes the total temperature change in the soil by estimating temperature profiles before and after the thawing (in his case freezing) season. In dry soils the soil warming may be very significant and his solution is useful.

Active layer calculations suffer from some mathematical simplifications but their greatest drawback is in the estimation of the ground surface temperature from air temperature (Scott, 1964). In most cases,

field data and verification will be required. Temperature sensing probes installed in the ground give temperature profiles from which the active layer can be interpolated while "frost tubes" can be utilized to indicate the frozen and thawed layers. The thaw depth may be directly measured by driving a steel rod or hand augering into the ground to refusal. Holes may be drilled with mechanical equipment to obtain the same information. Many of the methods for mapping and predicting permafrost, including as yet experimental geotechnical methods, are reviewed by Ferrians and Hobson (1973).

Quasi-static solution

The steady state solutions provide only the long term effects. The thawed zone dimensions at any time, as a result of a step change in surface temperature, can be estimated using a quasi-static solution. The steady state solutions are assumed valid in the frozen and thawed zones, but the thaw interface moves with time. The latent heat contribution is assumed to dominate, which would be the case in soils with high water (ice) content. Porkhayev (1963) and Thornton (1974) have presented graphs which facilitate solution of the problem for a number of conditions and Thornton includes a solution for the more useful case of an insulated pipe. This solution is important when there is a large thawed zone created by the pipes and only the thawing within the design life of the system is required (Cameron, 1975B).

Numerical solutions

Recent interest in hot oil pipelines has produced a number of computerized time dependent numerical solutions to buried pipeline problems (e.g. Lachenbruch, 1970; Gold et al, 1972; and Jahns et al, 1974). These numerical methods can be used to solve the appropriate differential equations of heat flow and may include sophistications such as latent heat, temperature dependent soil thermal properties, particularly the unfrozen water content, and surface temperature conditions that follow a wide range of time functions or may be calculated by a surface heat balance given the climatic conditions.

These numerical solutions are very versatile and include many complex refinements, however, like any other mathematical solution

they are limited by the quantity and reliability of input data. Goodrich (1973) points out some of the approximations that are generally made, particularly the surface temperature, in even the most sophisticated solutions and in light of these questions the merit in further refining internal heat exchange aspects.

Presently the limited availability of these programs and the high cost involved in manpower and computing time limits their use to research and large design projects. It would be very useful to use these to check the simplified methods presented in this paper and perhaps establish simple factors that may be applied to more complicated soil and physical conditions so that the simplified solution may better approximate reality.

Superposition Solutions

The temperature field around a pipe is a result of the pipe itself and the fluctuating surface temperature. In many cases by analyzing these components separately and combining them, complex transient state conditions can be estimated. It should be realized, however, that the non-linear effects of latent heat and temperature dependent soil properties precludes direct addition of thermal influences. This type of solution is useful in calculating the heat loss from and the temperatures around a buried pipeline.

Heat loss

The superposition principal is used by Janson (1963) to calculate the heat loss from pipes when there is a temperature gradient in the ground. He suggests that, except for very shallow pipes, in the steady state equations the ground surface temperature be replaced with the natural ground temperature at the pipe depth. Krivoshein and Semonov (1967) in experiments with pipe depth to radius ratios from 2.5 to 6.0 found generally good but erratic agreement (3% to 38%) for various values of heat loss. If thawing around the pipe is considered, Petrunichev and Shadrin modified the equation by factoring the fluid temperature similar to Thornton (1976A). This equation was found to give excellent agreement in experiments reported by Konstantinov (1965). The equations in this form can be used to calculate the annual or instant-

aneous heat loss if the natural ground temperature at the pipe depth is known or can be estimated.

Temperatures and thawing around a buried pipe

The steady state temperatures around a pipe can be easily determined; however, there is no analytical solution to calculate the ground temperatures as a result of a sinusoidal surface temperature when latent heat is considered. If, however, only the ground below the active layer is considered the problem is greatly simplified. Also, in the case of maximum thawing prediction, we are only interested in the warmest ground temperatures which, remembering that these temperatures do not occur simultaneously, is given by the warm side of the Trumpet Curve (Figure 5). (See List of Symbols for definitions and units.)

$$T_Y = T_G + (T_0 - T_G) e^{-B(Y-A)} \quad \text{for } Y \geq A$$

The steady state ground temperatures as a result of a buried insulated pipe can be calculated on a coordinate basis from:

$$T_{(X,Y)} = T_G + (T_I - T_G) \frac{\ln \left(\frac{x^2 + (c - y)^2}{x^2 + (c + y)^2} \right)^{1/2}}{\ln \left(\frac{H_p + r_I + c}{H_p + r_I - c} \right)} \quad (2)$$

$$\text{where: } T_I = T_G + \frac{R_S}{R_I + R_S} (T_W - T_G) \quad (3)$$

$$R_S = \frac{\text{arccosh } (H_p/r_I)}{2 \pi K_S} \quad (4)$$

$$= \frac{\ln (2H_p/r_I)}{2 \pi K_S} \quad \text{for } H_p > 2r_I \quad (5)$$

$$R_I = \frac{\ln (r_I/r_p)}{2 \pi K_I} \quad (6)$$

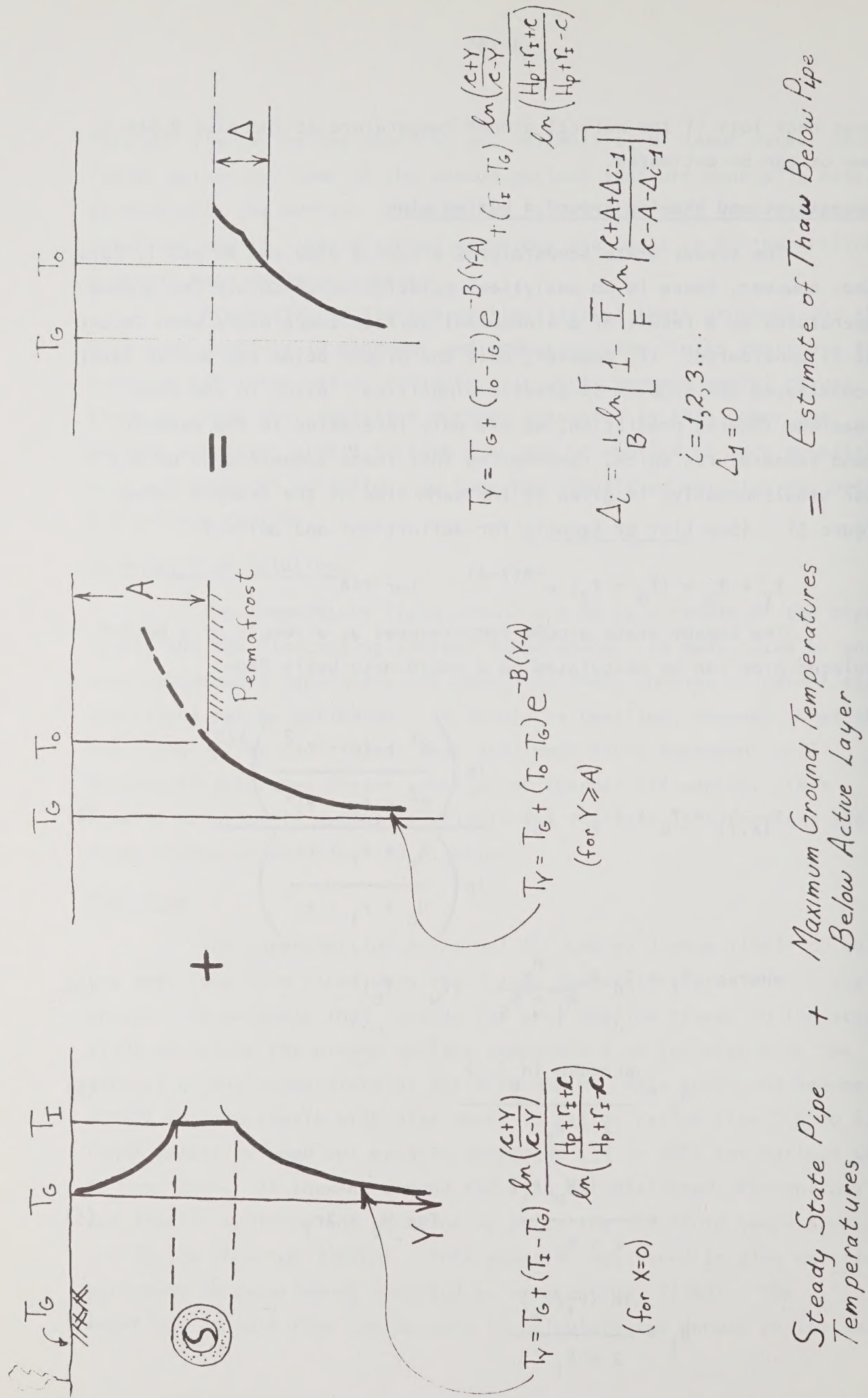


FIGURE 5. ESTIMATING THAW BELOW PIPE

For the case of an uninsulated pipe, replace r_p with r_l and T_w with T_l in all equations. The maximum ground temperatures below the active layer can therefore be estimated by combining these two influencing factors:

$$T_{(X,Y)} = T_G + (T_0 - T_G) e^{-B(Y-A)} + (T_l - T_G) \frac{\ln \left(\frac{X^2 + (c + Y)^2}{X^2 + (c - Y)^2} \right)^{1/2}}{\ln \left(\frac{H_p + r_l + c}{H_p + r_l - c} \right)} \quad Y \geq A \quad (7)$$

This equation can be solved with a programable calculator or simple computer solution, such as used for Figures 2 and 3, to determine the depth and extent of thawing and thermal perturbation. The resulting maximum thaw depth below the pipe is of the greatest interest and this may be obtained by rearranging Equation (7) to obtain the following equation which must be iterated.

$$\Delta_i = -\frac{1}{B} \ln \left[1 - \frac{\bar{T}}{F} \ln \left(\frac{c + A + \Delta_{i-1}}{c - A - \Delta_{i-1}} \right) \right] \quad \begin{aligned} i &= 1, 2, 3, \dots \\ \Delta_1 &= 0 \\ \Delta &\leq A \text{ (Generally)} \end{aligned} \quad (8)$$

The pipe and insulation parameters are generally known to a high precision but the mean annual ground temperature and the active layer depth after construction are difficult to estimate. A range may be estimated and computations for a number of values made.

Since this equation adds the steady state pipe effects to the warmest influence of the transient surface conditions the results will tend to over-estimate the thermal perturbation and in particular the thawing as a result of the warm pipe. In most cases this is desirable for engineering estimates, but where the thawing is large a more detailed numerical solution may be required. This simple equation is, however, useful in obtaining a better understanding of the problem and the relationship between and relative importance of the input parameters.

SUMMARY AND CONCLUSIONS

1. A piped utility system is the only alternative which provides an acceptable standard of water quantity, wastewater removal and system convenience and reliability for developing centres and may be the overall more economic system in many of the smaller communities.
2. There is no doubt that from a community planning and aesthetic point of view, buried utilities should be installed wherever practical. I believe that, except where foundation problems are severe, buried utilities will be the overall most economical system.
3. The beneficial synergistic effects of increased thickness of a near hydrophobic insulation, generally polyurethane, justify its liberal application around buried pipes in permafrost regions. This, along with shallow bury and other measures, can often reduce detrimental ground thawing to depths such that simple over excavation and replacement with non-frost susceptible soil will alleviate foundation problems. In unpredictable or unstable soils, piles or one of the passive measure may be utilized.
4. The criterion for practicability will often be the thermal perturbation as a result of the actual construction, and not the buried pipes. This is perhaps the most difficult thermal influence to estimate. In areas where an organic surface layer is important to the foundation soil stability, summer (thawing period) construction should be avoided and other construction and design techniques may also be necessary.
5. Due to construction difficulties, high ice content unstable soils and other local factors, buried utilities will not be practical, though technically possible, in many locations. The potential benefits warrant continued investigation into this area and every effort should be made to monitor and report on new systems, such as is being done at Frobisher Bay. However, more conclusive and generally applicable results would be obtained from a research field study designed to access various construction and design techniques.

LIST OF SYMBOLS

- A = Active layer thickness, ft (m)
 $B = \sqrt{\pi C_F / K_F p}$
 C = Volumetric heat capacity of soil, BTU/°F ft³ (J/K m³)
 $c = \sqrt{H_p^2 - r_I^2}$
 $F = \text{arccosh}(H_p / r_I)$
 $= \ln(2H_p / r_I)$ for $H_p > 2r_I$
 H = Depth of bury to centre of pipe, ft (m)
 K = Thermal conductivity, BTU/hr ft °F (W/mK)
 p = Time period of one year, (hr)
 Q = Rate of heat loss per unit length, BTU/hr ft (W/m)
 r = Radius, (ft)
 R = Thermal resistance, hr ft °F/BTU (mK/W)
 T = Temperature, °F (K)
 $\bar{T}$ = Temperature Ratio, $(T_I - T_0) / (T_0 - T_G)$
 Δ = Thaw perturbation below pipe, ft (m)

LIST OF SUBSCRIPTS

- | | | |
|---|-----------|--------------------------------|
| F | refers to | Frozen soil |
| G | " | Ground |
| I | " | Insulation around pipe |
| i | denotes | 1,2,3,... |
| 0 | refers to | (zero) Freezing point of water |
| P | " | Pipe |
| S | " | Soil |
| T | " | Thawed soil |
| W | " | Water (fluid) within pipe |
| Z | " | Zone of thaw |

REFERENCES

- Aldrich, H.P. and Paynter, H.M. (1953) Analytical studies of freezing and thawing of soils. U.S. Army, Arctic Construction and Frost Effects Laboratory, Technical Report N. 42.

Aldrich, H.P. and Paynter, H.M. (1966) Depth of frost penetration in non-uniform soil. U.S. Army, Cold Regions Research and Engineering Lab., Hanover, New Hampshire, Special Report 104.

Alter, A.J. (1969A) Water supply in cold regions. U.S. Army, Cold Regions Research and Engineering Lab., Hanover, New Hampshire, Monograph III-C5a.

Alter, A.J. (1969B) Sewage and sewage disposal in cold regions. U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Monograph III-C5b.

Anderegg, J.A., Hubb, G.L. and Eaton, E.R. (1960) Ice water on tap for the Arctic. Waterworks Engineering, Vol. 113, No. 7, p 632-634.

Anonymous (1966) Plastic foam insulates Yukon waterline. Engineering and Contract Record, March, p 29.

Anonymous (1967) Instructions for the design of townsites, factories, buildings, and structures in the northern construction climatic zone. National Research Council of Canada, Ottawa, Ontario, Technical Translation, NRC-TT-1547.

Associated Engineering Services Ltd., (1972A) A review of the proposed water and sanitation policy with recommendations on implementation. Prepared for: Dept. of Local Government, Government of the Northwest Territories, Yellowknife, N.W.T.

Associated Engineering Services Ltd., (1972B) Highway design concept construction practices and materials. Prepared for: Dept. of Public Works, Government of Canada, Ottawa, Ontario.

Associated Engineering Services Ltd., (1973A) Water and sewage system analysis - Town of Inuvik, N.W.T. Prepared for: Northern Canada Power Commission, Edmonton, Alberta.

Associated Engineering Services Ltd., (1973B) Proposal for buried utilities, Happy Valley, Inuvik, N.W.T. Prepared for: Arctic Technology Group, Environment Canada, Edmonton, Alberta.

Averill, D.W. and Heinke, G.W. (1973) Vacuum sewer systems for northern application. In: Symposium on Wastewater Treatment in Cold Climates, Saskatoon, Saskatchewan, Environment Canada Report No. EPS 3-WP-74-3, p 258-286.

- Bakakin, V.P. and Porkhaev, G.V. (1959) Principal methods of moisture thermal amelioration of the ground over large areas. National Research Council of Canada, Technical translation, NRC-TT-1250.
- Bohlander, T.W. (1963) Electrical method for thawing frozen pipes. Journal of the American Water Works Association, Vol. 55, No. 5, p 602-608.
- Bureau of Yards and Docks (1955) Arctic engineering. Dept. of the Navy, Washington, D.C., Technical Publication Navydocks TP-PW-11.
- Cadario, P.M. and Heinke, G.W. (1972) Manual for trucking operations for municipal services in communities of the Northwest Territories (Revised draft). Northern Science Research Group, Dept. of Indian and Northern Affairs, Ottawa, Ontario.
- Cameron, J.J. (1975A) Buried utilities in permafrost regions. Special report to: Institute of Water Resources, University of Alaska, Fairbanks, Alaska.
- Cameron, J.J. (1975B) Shallow buried utilities in cold regions. Report to: Technology Programs, Technical Branch, Environmental Protection Service, Environment Canada, Edmonton, Alberta.
- Carefoot, E.I. (1975) Personal communications, Associated Engineering Services Ltd., Edmonton, Alberta.
- Carcich, I.G., Hetling, L.J., and Farrell, R.P. (1972) A pressure sewer system demonstration. U.S. Environmental Protection Agency, Washington, D.C., EPA-R2-72-091.
- Carslaw, H.S. and Haeger, J.C. (1959) Conduction of heat in solids. Oxford University Press, 2nd Ed.
- Chapman, F.S. and Holland, F.A. (1966) Keeping piping hot, Part II, By heating. Chemical Engineering, January 17, p 133-134.
- Chemelex (1970) Electro-Wrap heat tracing system. Brochure: Chemelex, 837 Second Avenue, Redwood City, California.
- Cheriton, W.R. (1966) Electrical heating of a water supply pipeline under arctic conditions. Engineering Journal, Vol. 49, No. 9, p 31-35.
- Chernyshoff, M.J. (1930) Water services in regions with perpetually frozen ground. J. American Water Works Association, Vol. 22, No. 7, p 899-911.

Churakov, B.H. (1959) Installation of sanitary engineering utilities in permafrost. Translation available from National Science Library, Ottawa, Ontario.

Copp, S.S., Crawford, C.B. and Grainge, J.W. (1956) Protection of utilities against permafrost in northern Canada. J. of American Water Works Association, Vol. 48, No. 9, p 1115-1166.

Crory, F.E. (1973) Settlement associated with the thawing of permafrost. In: North American Contribution, Second International Conference on Permafrost, Yakutsk, U.S.S.R., p 599-607.

Dawson, R.N. and Slupsky, J.W. (1968) Pipeline research water and sewer lines in permafrost regions. Dept. of National Health and Welfare, Edmonton, Alberta, Manuscript Report No. NR-68-8.

Dean, R.C. (1962) Drilling and excavating frozen soil. U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, N.H., Technical Note 18.

Deans, B. and Heinke, G.W. (1972) Household and community waste disposal for northern communities. Dept. of Civil Engineering, University of Toronto, Toronto, Ontario.

Durnovo, V.B. (1969) Construction of public utilities lines in Western Siberia. *Straitelstvo truboprovodov*, No. 4, p 25-26 In: A Survey of Soviet Pipeline Construction Techniques and Related Activities in Western Siberia, Translated by Williams Brothers Engineering Company, Tulsa, Oklahoma.

Ewing, R.C. (1974) Alyeska pipeline tests chain saw rock cutter. Oil and Gas Journal, Vol. 72, No. 11, p 92.

Fiberlite Products Co. Ltd. (1975) U-Dor. Brochure: Box 5787, Station L, Edmonton, Alberta.

Ferrains, O.J. and Hobson, G.D. (1973) Mapping and predicting permafrost in North America: A review 1963-1973. In: North American Contribution Second International Permafrost Conference, Yakutsk, U.S.S.R., p 479-498.

Foster-Mill Associates Ltd. (1973) Fundamental concepts for the rapid disengagement of frozen soil. U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, N.H.

Foster, R.R. (1974) Arctic water supply; The Cape Dorset and Rankin Inlet systems. Presented at: 1974 Western Canada Water and Sewage Conference, Calgary, Alberta.

Fryer, W.F. (1970) The buried pipe problem (Quick solutions to selected problems in heat transfer). Inst. of Arctic Environmental Engineering Univ. of Alaska, College, Alaska, Publication B7002.

Gamble, D.J. (1976) Unlocking the utilidor: Northern utilities design and cost analysis. Presented at: Utilities Delivery in Arctic Regions Symposium, Northern Technology Centre, Environmental Protection Service, Environment Canada, Edmonton, Alberta.

Gamble, D.J., and Lukomskyj, P. (1975) Utilidors in the Canadian North. Canadian J. of Civil Engineering, Vol. 2, No. 2, p 162.

Giles, S. (1956) A proposed system of utility piping installation in snow, ice and permafrost. Naval Civil Engineering Lab., Port Hueneme, Calif., N-261.

Gilpin, R.R. and Faulkner, M.G. (1974) Thermal expansion compensation in aboveground water piping systems for low temperature environments. Prepared for: Environmental Protection Service, Environment Canada, Edmonton, Alberta.

Gold, L.W., Johnston, G.H., Slusarchuk, W.A. and Goodrich, L.E. (1972) Thermal effects in permafrost. In: Proc. of Canadian Northern Pipeline Research Conference, National Research Council of Canada, Ottawa, Ontario, Technical Memorandum No. 104, p 25-45.

Gold, L.W. and Lachenbruch, A.H. (1973) Thermal conditions in permafrost - A review of North American literature. In: North American Contributions, Second International Permafrost Conference, Yakutsk, U.S.S.R., p 23-25.

Goodrich, L.E. (1973) Computer simulations. Appendix to: Thermal Conditions in Permafrost - A Review of North American Literature, Gold, L.W. and Lachenbruch, A.H., In: Proceedings of the Second International Conference on Permafrost, North American Contribution.

Government of the Northwest Territories (1973) Proposed water and sanitation policy for communities in the Northwest Territories. Department of Local Government, Government of the Northwest Territories, Yellowknife, N.W.T.

Grainge, J.W. (1968) Solutions to northern insanitary conditions. Dept. of National Health and Welfare, Edmonton, Alberta, Manuscript Report No. NR-68-6.

Grainge, J.W. (1969) Arctic heated pipe water and wastewater systems. Water Research, Pergamon Press, Vol. 3, pp 47-71.

Grainge, J. (1974) Engineering for the North - Keeping the essential services flowing. Heavy Construction News, July 22, p 22-23.

Grainge, J.W. and Shaw, J.W. (1971) Community planning for satisfactory sewage disposal in permafrost regions. Presented at: Second International Symposium on Circumpolar Health, Oulu, Finland.

Highway Research Board (1952) Frost action in soils - A symposium; Highway Research Board, Special Report No. 2.

J.L. Richards and Associates Ltd. (1974) Hamlet of Frobisher Bay - Design report for sanitary sewers, water mains and waste water treatment. Report to: Government of the Northwest Territories, Yellowknife, N.W.T.

Jacobsen, G. (1973) The design of utilidors. In: Building in Northern Communities, Arctic Institute of North America, Calgary, Alberta.

Jahns, H.O. Miller, T.W., Power, L.D., Rickey, W.P. Taylor, T.P., and Wheeler, J.A. (1973) Permafrost protection for pipelines. In: North American Contributions, Second International Permafrost Conference, Yakutsk, U.S.S.R. p 673-684.

James, F. (1976) Personal communications, Dept. of Public Works, Government of the N.W.T., Yellowknife, N.W.T.

Janson, L.R. (1963) Water supply systems in frozen ground. In: Proc. International Permafrost Conference, Lafayette, Indiana, p 403-433.

Janson, I.E. (1964) Frost penetration in sandy soil. Royal Institute of Technology, Stockholm, Sweden, Translation No. 231.

Janson, L.E. (1968) Ground frost penetration in Sweden. National Research Council of Canada, Ottawa, Ontario, Technical Translation, TT-1532.

Jespersen, F. (1973) Vacuum sewage transport and treatment in rural areas in Denmark. In: Symposium on Wastewater Treatment in Cold Climates, Saskatoon, Saskatchewan, Environment Canada Report No. EPS 3-WP-74-3, p 287-304.

- Johnson, P.R. (1970) The IAEE heat sink refrigeration system. In: Proc. Symposium on Cold Regions Engineering, Univ. of Alaska, College, Alaska, p 622-631.
- Kamenskii, R.M. (1965) Heat exchange on filling a water main placed in frozen soil. National Research Council of Canada, Ottawa, Ontario, Draft Translation.
- Klassen, H.P. (1960) Water supply and sewerage system at Uranium City. Engineering Jr., Vol. 43, No. 9, p 61-65.
- Klassen, H.P. (1965) Public utilities problems in the discontinuous permafrost areas. Proceedings of the 2nd Canadian Regional Conference, National Research Council of Canada, Technical Memo No. 86, p 106-118.
- Konstantinov, I.P. (1965) Experimental heat exchange between a partially filled pipeline and frozen ground. National Research Council of Canada, Ottawa, Ontario, Draft Translation.
- Kritz, M.A., and Wechsler, A.E. (1967) Surface characteristics effect on thermal regime - Phase II. U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, H.H., TS-189.
- Krivoshein, B.L. and Semenov, L.P. (1967) Experimental studies of heat transfer from pipes lain in the ground. Translated by Associated Technical Services Inc., RJ-4987.
- Lachenbruch, A.H. (1959) Periodic heat flow in a stratified medium with application to permafrost problems. U.S. Dept of the Interior, Washington, D.C., Geological Survey Bulletin 1083-A.
- Lachenbruch, A.H. (1970) Some estimates of the thermal effects of a heated pipeline in permafrost. U.S. Department of the Interior, Washington, D.C., Geological Survey Circular 632.
- Lamphere, E.M. (1953) Flush tanks used to prevent sewer freezing. Sewage and Industrial Wastes, vol. 25, No. 1, p 100-102.
- Lange, G.R. (1964) Additional data on the effectiveness of various means of cutting frozen soil, rock and ice. U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, N.H., Unofficial Memorandum (unpublished).

Lawrence, N.A. (1969) Utility systems in Northern Canada. The Northern Engineer, Vol. 1, No. 4, p 4-7.

Lawrence, N.A. (1970) On the human aspects of cold climate operations. Presented at 99th Annual meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Dallas, Texas.

Legget, R.F. and Crawford, C.B. (1952) Soil temperatures as they affect waterworks practice. J. American Water Works Association, Vol. 44, No. 10.

Letch, A.F. and Heinke, G.W. (1970) Comparison of Utilidors in Inuvik, N.W.T. Dept. of Civil Engineering, Univ. of Toronto, Ontario.

Linell, K.E. and Johnston, G.H. (1973) Engineering design and construction in permafrost regions - A review. In: North American Contribution, Second International Conference on Permafrost, Yakutsk, U.S.S.R., 553-577.

Lukomskyj, P. and Thorton, D. (1975) Piping systems. In: Permafrost Engineering Manual - Design and Construction. National Research Council of Canada, Ottawa, Ontario, (In press).

Miller, J.M. (1970) Pile foundations in thermally fragile frozen soil. In: Proc. Symposium on Cold Regions Engineering, Univ. of Alaska, College, Alaska, p 34-72.

Muller, S.W. (1947) Permafrost or permanently frozen ground and related engineering problems. J.W. Edwards Inc., Ann Arbor, Michigan.

Murphy, R.S. and Hartman, C.W. (1969) A water distribution system for cold regions. Inst. of Water Resources, Univ. of Alaska, College, Alaska, Report No. IWR-8.

McCullough, C.R. (1958) Review of frozen ground excavation methods. U.S. Army, Snow Ice and Permafrost Research Establishment, Technical Report 51.

McKay, A.R. (1971) Practical heat transfer calculations for arctic engineers. In: Proc. Symposium on Cold Regions Engineering, Univ. of Alaska, College, Alaska, p 12-32.

Mytolon Chemical Int. Ltd. (---) Poleset. Brochure: 54 Shephard Road, Oakville, Ontario.

Nixon, J.F. and McRoberts, E.C. (1973) A study of some factors affecting the thawing of frozen soils. Canadian Geotechnical J., Vol. 10, No. 3, p 439-452.

Orlov, V.A. (1966) The problem of heat supply in settlements in the permafrost regions. In: Problems of the North, No. 10, National Research Council of Canada, Ottawa, Ontario, Technical Translation.

Orr, R. and Smith, D. (1976) Self contained toilet units. Presented at Utilities Delivery in Arctic Regions Symposium, Northern Technology Centre, Environment Canada, Edmonton, Alberta.

P.A.T. (---) Positive aqua thawing. Brochure: Western Water and Sewer Supplies Ltd., Edmonton, Alberta.

Reed, S.C. (1967) Planning utility systems in arctic and sub-arctic communities. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H., Internal Report.

Rice, E. (1972) Permafrost: Its care and feeding. The Northern Engineer, Vol. 4, No. 2, p 21-26.

Royle, J.C. (1970) Careful planning cuts costs at Fermont. Heavy Construction News, Oct. 15, p 26.

Pipe Heating Systems Ltd., (---) Skin effect current tracing. Brochure: P.O. Box 174, St. Thomas, Ontario.

Rogness, D. and Ryan, W. (1976) Vacuum sewage collection in the Arctic: Norvik, Alaska - A case study. Presented at: Utilities Delivery in Arctic Regions Symposium, Northern Technology Centre, Environmental Protection Service, Environment Canada, Edmonton, Alberta.

Porkhaev, G.V. (1959A) Underground utility lines. Translated by National Research Council of Canada, Ottawa, Ontario, Technical Translation, NRC TT-1221.

Porkhaev, G.V. (1959B) Permafrost Studies - Thermal physical principles of controlling the interaction between structures and frozen soil. National Research Council of Canada, Technical Translation, NRC-TT-1249

Porkhayev, V.A. (1963) Temperature fields in foundations. In: International Permafrost Conf., Lafayette, Indiana, p 285-292.

Ryan, W.L. (1973) Design and construction of practical sanitation facilities for small Alaskan communities. In: North American Contribution, Second International Permafrost Conference, Yakutsk, U.S.S.R., p 721-730.

Ryan, W. and Rogness, D. (1976) Pressure sewage collection system in the arctic. Presented at: Utilities Delivery in Arctic Regions Symposium, Northern Technology Centre, Environmental Protection Service, Environment Canada, Edmonton, Alberta.

Rybczynski, W. and Ortega, A. (1973) Stop the five gallon flush. Minimum Cost Housing Group. School of Architecture, McGill University, Montreal, Quebec.

Saltykov, NoI. (1944) Sewage disposal in permafrost in the far North of the European portion of the U.S.S.R. Translated for U.S. Army, Corps of Engineers, 1950.

Saltykov, N.I. and Prokhaev, G.V. (1959) Permafrost studies - Bases and foundations, National Research Council of Canada, Technical Translation, NRC-TT-1266.

Sanger, F.J. (1969) Foundations of structures in cold regions. U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, N.H., Monograph III-C4.

Scott, R.F. (1964) Heat exchange at the ground surface. U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, N.H., Monograph II-A1.

Speer, T.L., Watson, G.H. and Rowley, R.K. (1973) Effects of ground-ice variability and resulting thaw settlement on buried warm-oil pipelines. In: North American Contribution, Second International Conference on Permafrost, Yakutsk, U.S.S.R., p 746-758.

Stanley, D.R. (1965) Water and sewerage problems in discontinuous permafrost areas. Proceedings of the 2nd Canadian Regional Permafrost Conference, National Research Council of Canada, Technical Memo. No. 86, p 93-105.

State Committee of the Council of Ministers for Building Problems (1964), Guide for design and construction of pile foundations in permafrost.

National Research Council of Canada, Ottawa, Ontario, Technical Translation, NRL-TT-1314.

The Dow Chemical Company (---) A system for protecting permafrost from the thermal effects of a hot oil pipeline. Brochure: The Dow Chemical Company, Midland, Michigan.

Thermon Canada Ltd., (---) Econotrace. Brochure: Thermon Canada Ltd., 431 Newbold St., London, Ontario.

Thronton, D.E. (1974) Some analytical and semi-analytical results on the thermal effects of a pipeline in permafrost. Environmental Protection Service, Environment Canada, Edmonton, Alberta, Unpublished.

Thornton, D.E. (1976A) Calculation of heat loss from pipes. Presented at Utilities Delivery in Arctic Regions Symposium, Northern Technology Centre, Environmental Protection Service, Environment Canada, Edmonton, Alberta.

Thornton, D.E. (1975B) Computer programs developed for Technology Programs, Technical Branch, Environmental Protection Service, Environment Canada, Edmonton, Alberta.

Tobiasson, W. (1971) Utility tunnel experience in cold regions. American Public Works Association, Special Report No. 41, p 125-138.

U.S. Public Health Service (1958) Monograph No. 54, PHS Publication No. 591.

Underwood McLellen and Associates Ltd. (1974) Study of pollution control system for Resolute, N.W.T. Prepared for: Environment Canada and Government of the Northwest Territories.

Zelenin, A.N. (1959) Cutting of soils. Publishing House of the Academy of Sciences of the U.S.S.R., Moscow, Translated by Creare Inc., Hanover, New Hampshire.

Zenger, N.M. (1965) Ways in which to improve the economics of water supply in the northern regions. In: Problems of the North, National Research Council of Canada, Ottawa, Ontario, No. 9.

Zhukov, V.F. (1958) Installation of sanitary engineering utilities in permafrost regions. Translated by J.A. Kerr, Dept. of National Health and Welfare, Edmonton, Alberta, Canada.

GROUND BEHAVIOUR DUE TO FREEZING AND THAWING

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INTRODUCTION

Analytical and experimental studies in support of the design of arctic oil and gas pipelines have contributed greatly to our understanding of the behaviour of ground during freezing and thawing. In the case of both an oil and a gas pipeline there are many reasons in favour of burial of the pipeline and the implications of the thermal interaction of the pipeline on the adjacent soil must be considered in design. Oil pipelines are planned to operate well above the freezing point of water and will create thaw in adjacent permafrost. Where the permafrost is a dense, low ice content material little subsidence will ensue and significant extra strains are not induced in the pipe due to the degradation of the permafrost. However, ice-rich fine grained permafrost exhibits substantial thaw-settlement characteristics and the consideration of the influence of this settlement on the strains developed in the pipe is a matter of considerable importance in the design of the pipe and the establishment of burial criteria. Thaw induced consolidation and settlements are also of concern in the evaluation of slope stability, drainage and erosion measures and other factors.

In the case of Arctic gas pipelines it is planned to chill the gas below freezing where it traverses permafrost in order to inhibit degradation. However, the chilled gas pipeline will cross areas of unfrozen soil such as exist both beneath permanent bodies of water and throughout the discontinuous zone. Here freezing will ensue. One of the design considerations in this case is frost heave. Frost susceptible soils attract water to the freezing front and can, under certain conditions, develop substantial heave movements. Differential frost heave will cause strain in a pipeline and design measures have had to be developed to analyse this behaviour and to suppress heave where necessary. Calculations

for both freezing and thawing of ground require the solution of heat conduction problems as well, in order to evaluate both settlement and heave phenomena. Hence, a considerable effort has also been devoted to the development of procedures for solving thermal problems.

The following reviews major recent developments in solving practical thermal problems and predicting the behaviour of the ground during freezing and thawing. Experience is drawn mainly from studies related to arctic pipelines but the developments are generally applicable to the design of utilities and other facilities in arctic regions.

HEAT CONDUCTION STUDIES

The equations describing the conduction of heat in soils accompanied by phase change are well-known. It is also generally agreed that for the solution of heat conduction problems where the strata may be non-uniform and the boundaries are irregular it is best to employ numerical methods of analysis based upon the finite element methods. Computer programs have been validated by comparing results with those available from closed form solutions (e.g., Hwang et al, 1972).

In order to obtain the solution to a given problem it is necessary to specify the thermal constants of the strata, the initial temperature condition, and the boundary conditions controlling the flow of heat when it is perturbed from the initial condition. Experience indicates that the thermal parameters of both frozen and unfrozen soil can be specified sufficiently well for geotechnical purposes if the moisture content and engineering classification of the soil are known. It is seldom necessary to know the temperature distribution everywhere in the ground in detail provided that the position of the 0°C isotherm is fixed reasonably accurately (Nixon and McRoberts, 1973).

When the boundary conditions are known with confidence comparisons between calculated temperatures and those observed in large scale field studies indicate that variations in ground temperature with time can be predicted extremely well. The most common boundary conditions that arise in pipeline design problems are those of a specified temperature on a boundary and those of a specified heat flux across a boundary. The

example of a buried oil pipeline illustrates the former. In this case the temperature of the flowing oil is specified at the outset and accurate calculations of the change in ground thermal regime can be made. Watson, Rowley, and Slusarchuk (1973) describe the performance of a warm oil pipeline buried in permafrost and they compare the observed and predicted positions of the thaw front. Even with relatively simple analyses, an acceptable degree of agreement is found. Many other examples exist that illustrate the application of numerical methods of heat conduction analysis to problems of practical interest (e.g., Kazemi and Perkins, 1971; Smith and Hwang, 1973).

The problem of calculating the change in ground thermal regime due to surface disturbance is more complex if the temperature at the ground surface is unknown. Surface disturbance alters the ground heat flux. But it also alters other components that enter into the energy balance at the ground surface. The ground heat flux is a minor component of the energy balance and errors in estimating other components such as net radiation and evapotranspiration will influence the accuracy of the estimate of the ground heat flux. Solutions to problems of this kind are being obtained using heat flux calculations or alternatively by obtaining equivalent temperature boundary conditions through approximate correlations between air temperature and surface ground temperature. The accuracy in predicting changes in ground thermal regime is less impressive although still adequate for most geotechnical purposes. Jahns et al (1973) discuss the factors that enter into specifying a flux boundary condition and illustrate the application of thermal analyses to a variety of problems associated with pipelines in permafrost.

THAW SETTLEMENT STUDIES

When permafrost thaws, settlements develop. Tests can be performed to isolate the parameters describing the amount of thaw induced settlements for a given soil. The magnitude of these parameters varies with the ice content of the soil, its structure and its history. In practice the estimate of the amount of thaw settlement is straight forward provided that the flow of water out of the soil is unimpeded. Difficulties

arise in obtaining enough soil data to be representative of a particular site. For preliminary design purposes a correlation can be developed between the thaw induced strain of a soil and its frozen bulk density, but as Speer et al (1973) pointed out local variability precludes an accurate estimate of settlement without a considerable amount of site specific data. Methods of calculating settlement associated with the thawing of permafrost are discussed by Crory (1973).

When thawing is sufficiently rapid that the water generated by thaw cannot escape from the soil, load is transferred to the pore water and pore pressures develop. A theory of thaw consolidation is needed to lead to an understanding of the magnitude of these pore pressures and of their influence on the strength and deformation characteristics of thawing ground. Recent theoretical efforts have addressed these issues and have brought the level of thaw-consolidation theory to one comparable with that of the theory of consolidation in unfrozen ground. Experiments have provided evidence to support the validity of the theory and it is finding use in a variety of practical applications (Morgenstern and Nixon, 1971; Morgenstern and Smith, 1973).

Data collected at a warm-oil test pipeline in Inuvik, N.W.T. have been analysed making use of the theory of thaw-consolidation. The observed pore pressures, settlements, and rate of melting in the thawing permafrost foundation were compared with their corresponding theoretical predictions. Bearing in mind the natural variability of ice-rich permafrost deposits, the agreement between prediction and observation is extremely encouraging (Morgenstern and Nixon, 1975).

FROST HEAVE STUDIES

Frost heave phenomena in fine grained soil have been the subject of considerable study, particularly with reference to the design and performance of roads and runways. The factors influencing frost heave are well known and it is generally agreed that certain soil characteristics and availability of water to flow to the freezing front are among the most important. However there is no generally agreed set of equations that couple heat flow, moisture flow, and soil volume changes in a way that can be used for the detailed prediction of frost heave in any set of circumstances.

Recent research has drawn attention to the relation that exists between rate of heave and surcharge pressure for a given soil and a given rate of heat extraction. Moderate applied loads can inhibit the suction phenomena in freezing soils very substantially (Arvidson and Morgenstern, 1974). These studies have lead to the result that it is possible to contain frost heave of a buried chilled pipeline within tolerable limits. In frost-susceptible soils this can be achieved by a combination of surcharge loading and the effects of burial due to the weight of the native soil above the freezing front.

SUMMARY

While the understanding of ground behaviour due to freezing and thawing has advanced rapidly in recent years, particularly with regard to theoretical and laboratory studies, more well-documented case studies applying these developments to a variety of soil and thermal conditions are needed in order to establish the level of confidence associated with the utility of these developments in practice.

REFERENCES

- Arvidson, W.D. and Morgenstern, N.R., 1974. Water flow induced by soil freezing. Proc. 27th Can. Geotech. Conf., p 137-143.
- Crory, F.E., 1973. Settlement associated with the thawing of permafrost. Proc. 2nd Int. Conf. Permafrost, North American Contribution, p 599-607, National Academy of Sciences.
- Hwang, C.T., et al, 1972. A thermal analysis for structures on permafrost. Can. Geotech., Vol. 9, p 33-46.
- Jahns, H.O., et al, 1973. Permafrost protection for pipelines. Proc. 2nd Int. Conf. Permafrost, North American Contribution, p 673-683, National Academy of Sciences.
- Kazemi, H. and Perkins, T.K., 1971. A mathematical model of thaw-freeze cycles beneath drilling rigs and production platforms in cold regions. J. Pet. Tech., p 381-390.
- Morgenstern, N.R. and Nixon, J.F., 1971. One dimensional consolidation of thawing soils. Can. Geotech., Vol. 8, p 558-565.

Morgenstern, N.R. and Nixon, J.F., 1975. An analysis of the performance of a warm oil pipeline in permafrost, Inuvik, N.W.T. Can. Geotech. Vol. 12, p 199-208.

Morgenstern, N.R. and Smith, C.B., 1973. Thaw-consolidation tests on remoulded clays. Can. Geotech. Vol. 10, p 25-40.

Nixon, J.F. and McRoberts, E.C., 1973. A study of some factors affecting the thawing of frozen soils. Can. Geotech. Vol. 10, p 439-452.

Smith, M.W. and Hwang, C.T., 1973. Thermal disturbance due to channel shifting, Mackenzie Delta, N.W.T., Canada. Proc. 2nd Int. Conf. Permafrost, North American Contribution, p 51-59, National Academy of Sciences.

Speer, T.L., et al, 1973. Effects of ground-ice variability and resulting thaw settlements on buried warm-oil pipelines. Proc. 2nd Int. Conf. Permafrost, North American Contributions, p 746-751, National Academy of Sciences.

Watson, G.H., et al, 1973. Performance of a warm-oil pipeline buried in permafrost. Proc. 2nd Int. Conf. Permafrost, North American Contributions, p 759-766, National Academy of Sciences.

A STUDY OF PIPE FREEZING MECHANISMS

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INTRODUCTION

In designing water piping systems one would like to avoid having the piping exposed to a freezing environment; however, it is not always possible to avoid this situation. For example, in the installation of utility systems in northern communities the water mains and service piping are normally exposed to temperatures below 0°C and active measures must be taken to prevent freezing. Of course, passive measures such as the insulation of the pipes may also be taken; however, such measures by themselves will only lengthen the time taken for the pipes to freeze, they will not prevent freezing. Active measures must in some way add heat to the water piping system. This heat addition could take the form of heat tracers, either electrical or steam, or it could involve the continual heating and circulation of water through the piping system [1, 2, 3]. The latter method of heating may be achieved by having a double water main system (one out and one return), or by designing the water system as a loop, or merely by bleeding water from the water main into the sewer line at various points in the system. The heat required in the case of a heat tracer or the flow required in case of a circulating system can be calculated for most cases from standard handbook formulae such as exist in the ASHRAE Handbook of Fundamentals [4].

One problem, however, with a system that depends on an active method of freeze prevention, particularly as applied to a small isolated community, is the problem of the reliability of that system. The question that then arises is, "In the case of an equipment failure, how long will it be before the pipes freeze?" A partial answer to this question can be obtained by calculating the length of time required for the water to cool from its initial circulating temperature to the

freezing point. For example, water initially at 4°C in an insulated 6-inch water main in a utilidor surrounded by -30°C air would take about 12 hours to cool to 0°C . Formulae also exist from which the time required to freeze the pipe solid could be calculated [4]. For the water main of the previous example this time would be about nine days. In the formula used for calculating the time required to freeze the pipe it was assumed that the ice in the pipe formed an annulus growing in from the inside wall of the pipe. The implication is that until the pipe is frozen solid at some point in the system the water circulation could still be restarted and the ice thus melted out of the main. One would thus assume that at least part of the nine days required to freeze the pipe solid would be time when the flow could safely be restarted.

Unfortunately, the description of ice in a pipe as simply growing in from the walls of the pipe as an annulus is a gross oversimplification of the ice formation process that actually occurs in a pipe. As a result, it leads to some false conclusions about the behaviour of a freezing water pipe. In this paper the physical processes and the morphology of the ice that results during the freezing of a water pipe will be examined in detail. Also, some of the consequences of the real pipe freezing mechanism will be examined.

THE MECHANISM OF FREEZING

Figure 1 graphically shows the various stages in the time history of a freezing water pipe. As mentioned previously the rate decrease in the water temperature during the initial cool down period can be calculated at least approximately from the known heat loss through the insulation. Some irregularities occur in the cooling rate when the water passes through its maximum density point around 4°C [5]; however this has only a small effect on the overall cool down time. A most important observation is that the cool down period continues to water temperatures below freezing before the ice growth phase starts. This is the phenomenon of supercooling that is usually neglected in pipe freezing calculations. Actually, water must always be cooled below freezing before ice nucleation occurs. The actual amount of supercooling required before

PIPE CROSS SECTION

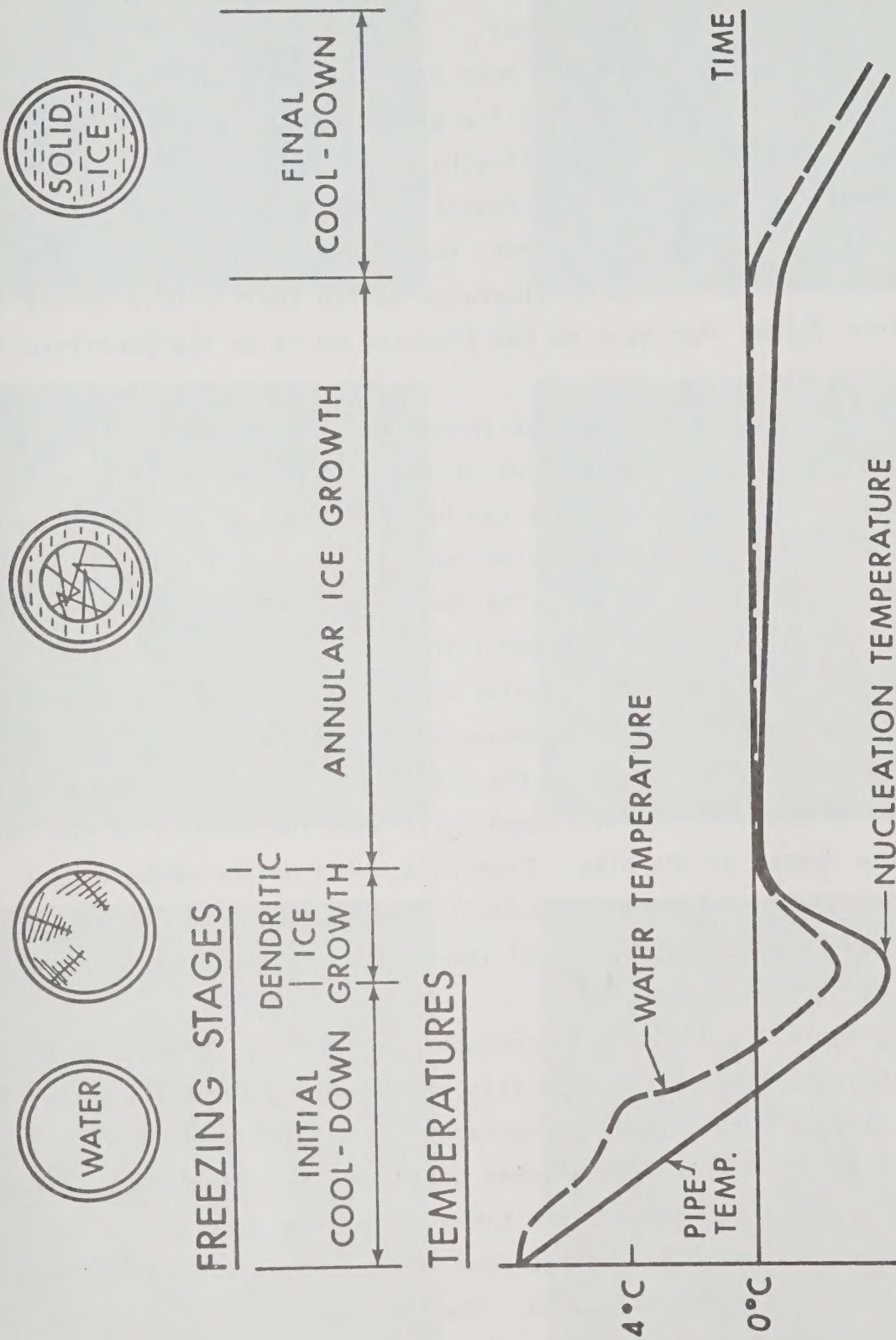


FIGURE 1. THE STAGES IN THE FREEZING OF A WATER PIPE

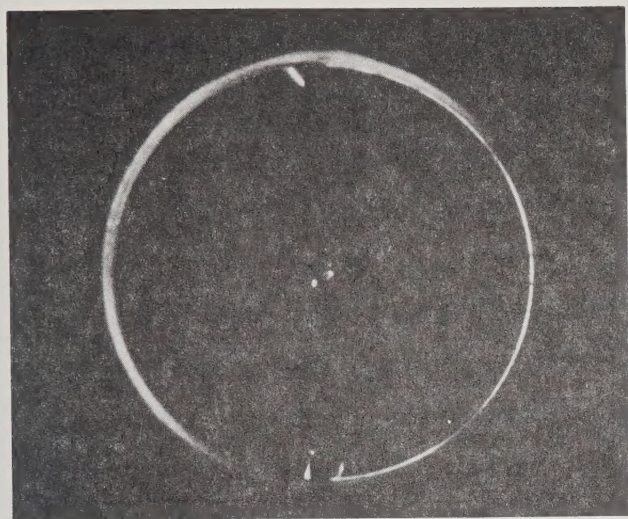
nucleation occurs will vary considerably depending on the circumstances; however, for ordinary water in a water pipe the nucleation temperature is usually -4 to -6°C . Some of the factors that influence the nucleation temperature will be discussed later.

When ice nucleates the next stage of the freezing process commences. This is the dendritic ice growth phase. Ice growing into supercooled water forms as thin 'feathery' crystals which are interspersed with the water. These dendritic crystals grow in a very short period of time, of the order of 30 seconds, to block the entire cross-section of a pipe. The heat of fusion liberated during their growth raises the temperature in the pipe back to the freezing point as the dendritic ice growth phase ends.

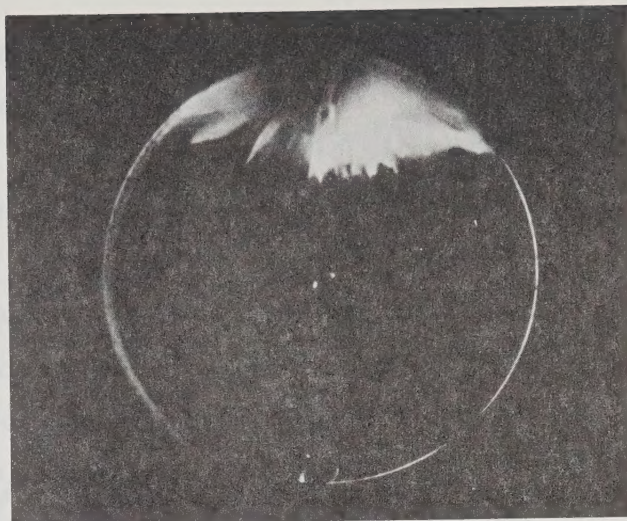
After the dendrites have formed further cooling of the pipe results in the growth of an annulus of ice in from the pipe walls. The growth of this annulus of ice can be calculated as mentioned previously. During the annular ice growth period some morphological changes are also occurring to the dendritic ice. The dendrites which grew as porous 'feathery' crystals are transformed into continuous thin sheets of ice which are now imbedded in the annular ring of ice around the pipe wall. These transformations have some consequences as far as the pressure required to break the ice out of the pipe is concerned.

The pipe is finally frozen solid when the annulus of ice has reached the center of the pipe. From this point on the temperatures in the pipe continue a more rapid decline as sensible heat is lost from the pipe and its ice contents until they are at equilibrium with the environment.

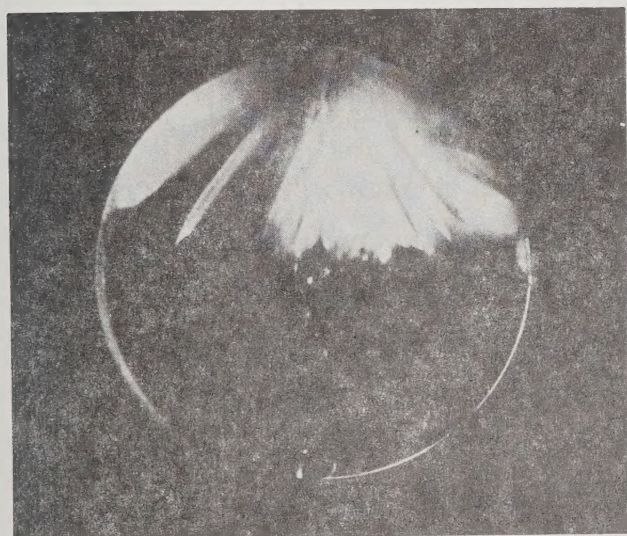
Figure 2 shows some photographs taken of ice forming in a pipe which visually show the dendritic and annular ice growth phases. The pipe used to obtain these photographs was a short length of 6" diameter pipe. The ends were blanked off with clear plexiglass windows through which the photographs were taken. The pipe section was filled with ordinary tap water and cooled from the outside. Figure 2a shows the pipe just before ice has nucleated. The thermocouple at the center of the pipe reads about -4°C at this point. The photographs 'b', 'c', 'd' and 'e' were taken in rapid succession over a time span of about



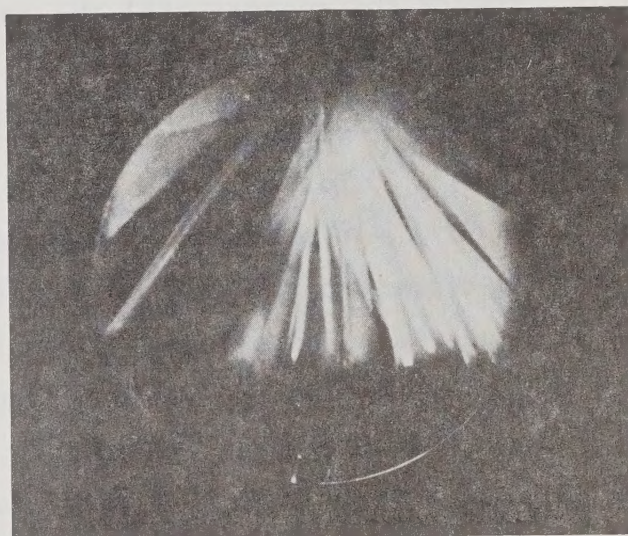
(a)



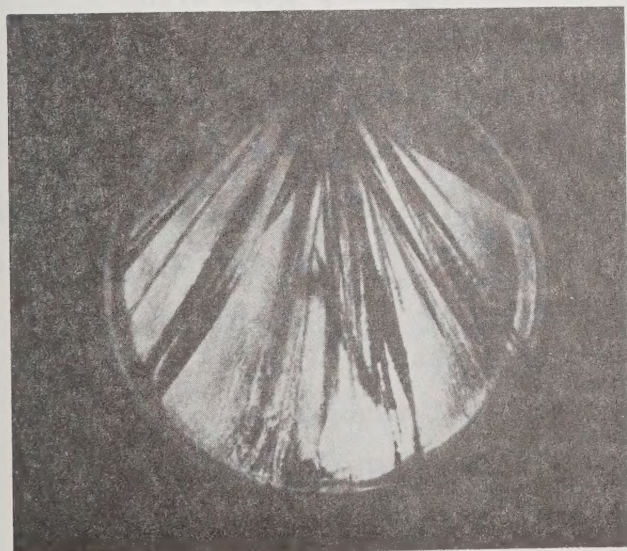
(b)



(c)



(d)



(e)



(f)

FIGURE 2. ICE FORMING IN A PIPE

30 seconds after the ice nucleated. They show the spread of ice dendrites from the nucleation center near the top of the pipe until they cover the whole pipe cross-section. It was observed that the ice growth usually started from the top of the pipe presumably because the coolest water in the pipe accumulates near the top during the cool down phase [5]. In photographs 'b' through 'c' which represent the dendritic ice growth phase the thin plate-like crystals of ice can be seen. Figure 2f shows a photograph of the same pipe taken 18 hours later. In this photograph an annulus of ice adjacent to the pipe walls can be seen in addition to the dendritic ice in the center of the pipe. If this test was continued the annulus of ice would continue to grow toward the center until the entire cross-section was solid ice.

THE EFFECTS OF DENDRITIC ICE GROWTH

To see if flow could be restarted in a pipe with dendritic ice in it a series of tests were done. In these tests copper pipes ranging in diameter from 1/4" to 1" I.D. and up to 10 feet long were used. These pipes were installed in a controlled temperature freezing chamber and cooled through the various stages of ice formation. The pressure gradient then required to blow the ice out of the pipe was measured. It was found that if a sufficient pressure gradient was applied to the pipe the flow could break through the dendritic ice in the pipe under some circumstances. When flow was restarted in a pipe with dendritic ice in it the first water coming from the pipe was a 'slush' composed of ice crystals and water. Some preliminary measurements of the pressure gradient required are plotted in Figure 3 as a function of the total heat lost from the water in the pipe after it had cooled through 0°C. The point at a heat loss of about 2.3 BTU/ft represents the condition at which the ice growth was nucleated in the pipe. The dendritic ice growth occurs very quickly and thus start-up pressure of about 0.5 psi/ft indicated for this point is the pressure gradient required to start flow immediately after dendritic ice growth has occurred. The initial part of the annular ice growth phase results in a rapid increase in the start-up pressure. At a total heat loss of about 13 BTU/ft, which represents an annulus of ice only about 0.06 inches thick, the pressure

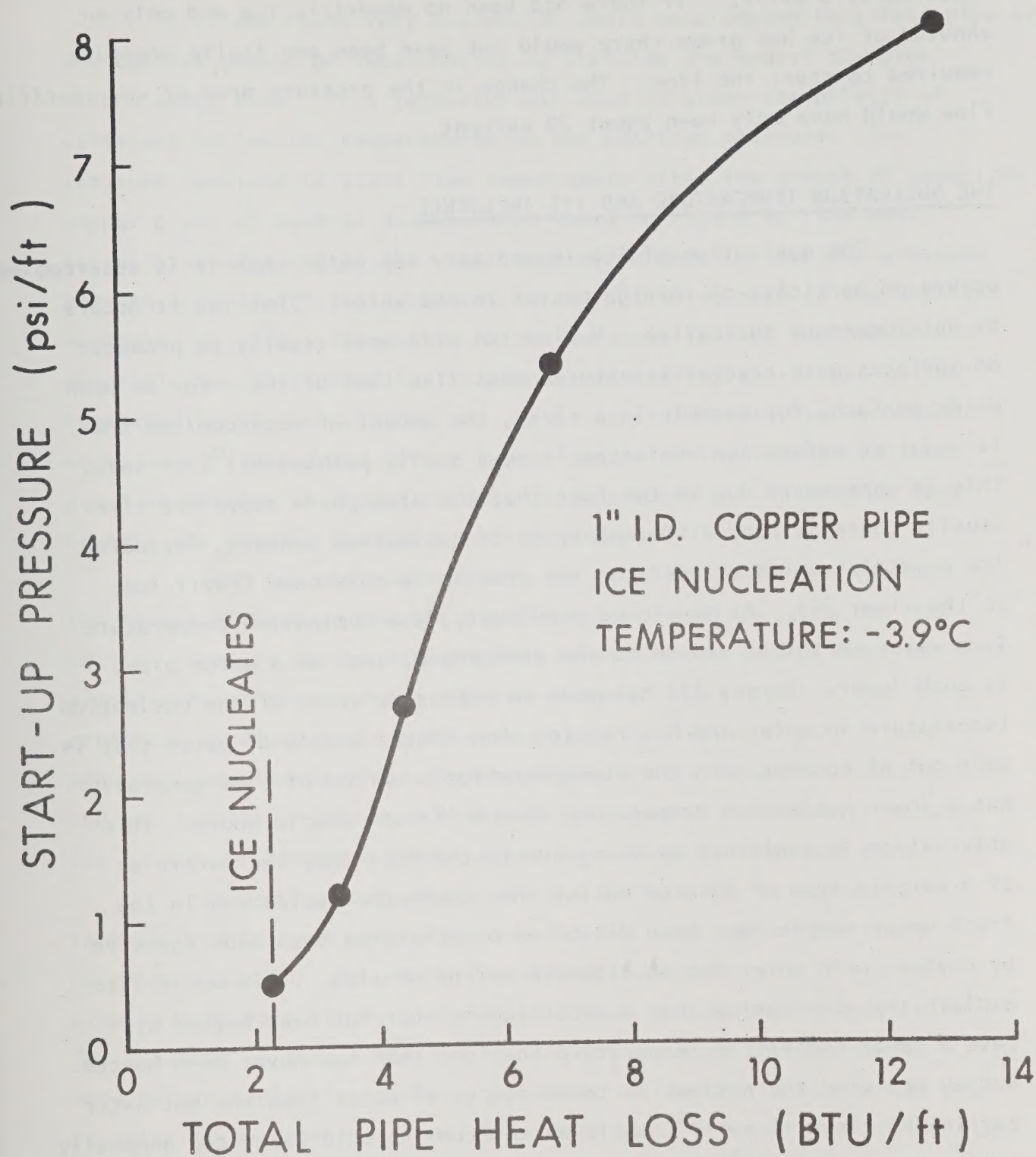


FIGURE 3. THE INCREASE IN THE START-UP PRESSURE DURING THE ANNULAR ICE GROWTH STAGE

required is 8 psi/ft. If there had been no dendritic ice and only an annulus of ice had grown there would not have been any finite pressure required to start the flow. The change in the pressure drop at any specified flow would have only been about 20 percent.

THE NUCLEATION TEMPERATURE AND ITS INFLUENCE

The nucleation of ice in ordinary tap water when it is supercooled occurs on particles of foreign matter in the water. That is, it occurs by heterogeneous nucleation. Nucleation will most readily be produced on surfaces with crystal structures most like that of ice. For an open water surface, for example in a river, the amount of supercooling that is required before ice nucleates is very small, perhaps 0.1°C or less. This is apparently due to the fact that the atmosphere above the river usually contains many different types of nucleation centers, including ice crystals, which trigger the ice growth, in this case frazil ice, in the river [6]. As mentioned previously, the nucleation temperature in a water container closed to the atmosphere, such as a water pipe, is much lower. Dorsey [7] has made an extensive study of the nucleation temperature in water and his results show that a sample of water that is kept out of contact with the atmosphere for a period of time generally has a lower nucleation temperature than a 'fresh' sample would. This observation is explained as being due to the fact that the particles of a certain type of foreign matter that cause the nucleation in the fresh water sample have been dissolved or otherwise been made inactive by contact with water for an extended period of time. This would also explain the observation that a water sample that has been heated will have a lower nucleation temperature than one that has never been heated. Dorsey measured the nucleation temperatures of water from the hot water tap in the range -6 to -7°C while water from the cold water tap generally nucleated at -4 to -5°C . Since the nucleation could be produced by extremely small amounts of a foreign matter, the measured nucleation temperatures may be expected to vary considerably between different places and times of observations. However, measurements made on Edmonton City water do show essentially the same values as those observed by Dorsey in Washington D.C.

It was found that nucleation could be produced in a test pipe at any desired amount of supercooling by striking the end of the pipe with a sharp blow. This technique was used to study the effects of different nucleation temperatures on the start-up pressure. The pressure required to start flow immediately after the growth of dendrites in copper pipes of several diameters is shown in Figure 4. The most striking observation is the very large difference in start-up pressure between a pipe with ice nucleated in at -3°C as opposed to one with ice nucleated at -5°C . The reason for this result is that the amount of dendritic ice that grows in the pipe is directly proportional to the supercooling of the water in it. As a result the dendrites are much more closely spaced and have a larger amount of interconnection when grown in water with larger amounts of supercooling. This would tend to make the overall dendritic matrix stronger.

From the observation that the start-up pressures required in the larger diameter pipes are significantly less than those for the smaller pipes it may be assumed that dendritic ice growth does not have significant effect in large diameter pipes. This, however, may be an erroneous conclusion since the start-up pressures in Figure 4 were measured immediately after the completion of the dendritic ice growth and the results in Figure 2 indicate that even a small amount annular ice growth can increase these values by a factor of ten and more.

Dorsey has suggested that the differences in nucleation temperatures between water from the hot and cold water taps could be responsible for the commonly observed phenomenon that a hot water pipe is much more likely to burst on freezing than a cold water pipe. The argument is that since the hot water pipe must be supercooled more before nucleation occurs, the amount of dendritic ice in the pipe is going to be greater. Thus water that must be forced out of the pipe to accommodate freezing during the annular ice growth phase would build up a greater pressure in a freezing hot water pipe than it would in a cold water pipe. To determine if dendritic ice could be responsible for pressures large enough to burst a pipe, the measurements of Figures 3 and 4 would have to be extended to much later stages of the freezing process. Such tests are underway. From the measurements in Figure 4,

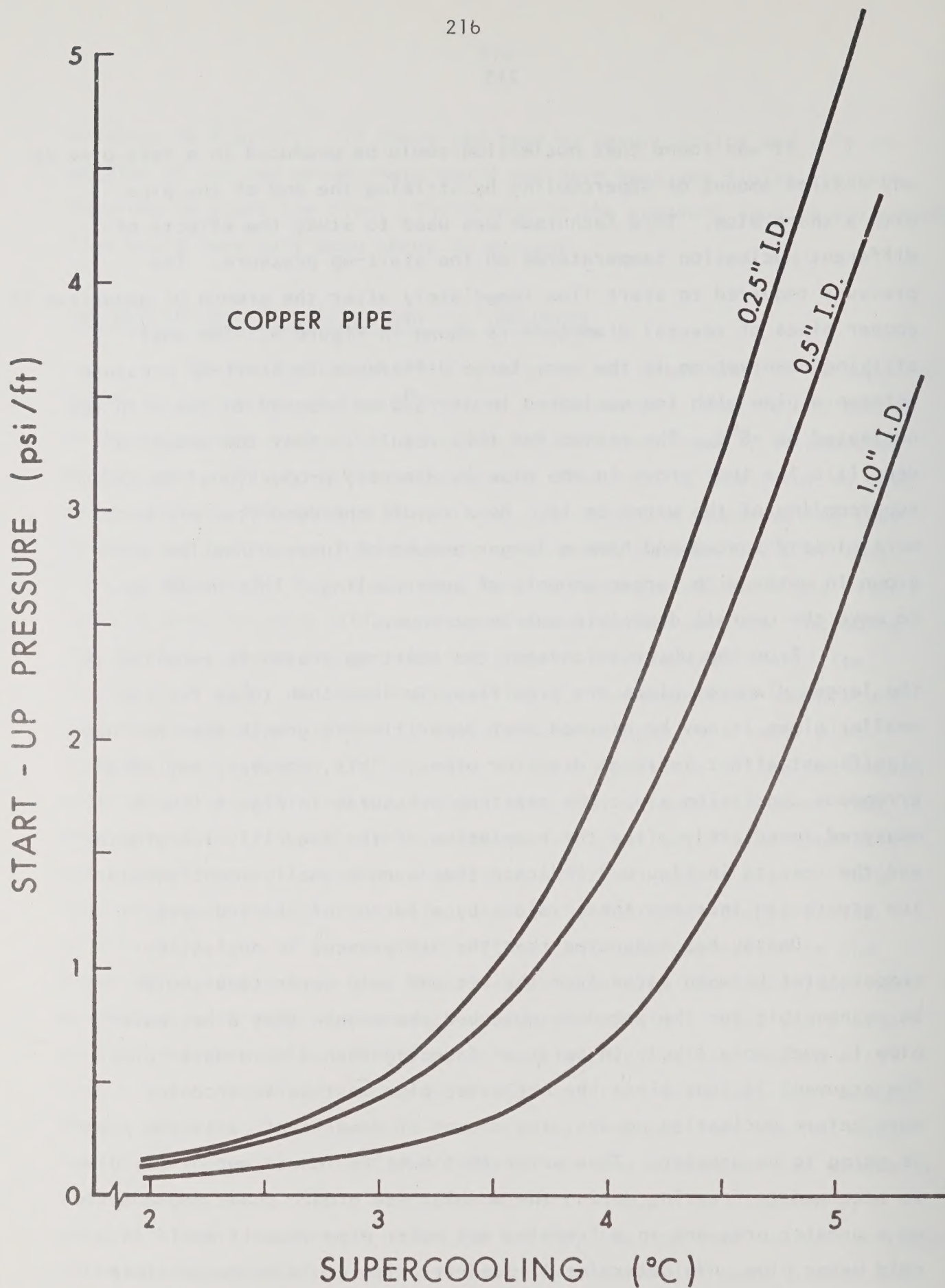


FIGURE 4. THE EFFECTS OF NUCLEATION TEMPERATURE AND PIPE DIAMETER ON THE START-UP PRESSURE

however, it would appear quite reasonable that a hot water pipe may be blocked by dendritic ice when there is still sufficient pressure to clear the cold water pipe.

THE EFFECT OF THE PIPE COOLING RATES

As illustrated in Figure 1 the temperature of the bulk of the water in a pipe will be higher than the temperature of the pipe wall during the initial cool down phase. The difference increases with both pipe diameter and cooling rate. This means that it may be that for a large diameter pipe and/or a high cooling rate, the pipe wall and the water immediately adjacent to it cool to the nucleation temperature before the water in the centre of the pipe has supercooled to any significant extent. In this situation dendritic ice growth only occurs near the wall and does not block the cross-section of the pipe. From previous experimental measurements [5] one would expect a significant reduction in the amount of dendritic ice growth in a 6-inch diameter water main if the cooling rate exceeded 4°C per hour and a decrease in a 1/2-inch water service line if the cooling rate exceeded 80°C per hour. These cooling rates would be produced in bare metal pipes exposed to air temperatures from -10 to -20°C .

This produces the potential for another interesting paradox. That is, a pipe with a small amount of insulation on it or in some other way protected from the elements, may become blocked by ice formation while a pipe without insulation and exposed directly to a cold environment may not be blocked. This could occur because the pipe with insulation would cool slower and thus the water in it would supercool more before nucleation occurred. The insulated pipe, therefore, would have more dendritic ice in it and would require a greater pressure to restart the flow even though the total heat loss from it was less. It is quite conceivable then that the line pressure would be sufficient to start the flow in the uninsulated pipe while it would be insufficient to start the flow in the insulated pipe.

EFFECT OF FLOW VELOCITY

Up to this point it has been assumed that there was no flow in the water pipe while it was freezing. The next question is "What would be the effect of flow?" As mentioned previously, striking a pipe with supercooled water in it causes ice to nucleate. In fact any disturbance will tend to cause nucleation. For example, it has been found that starting the flow of water in a supercooled pipe causes the ice to nucleate almost immediately. In this case a 'slush' ice is produced which may flow out of the tap with the first water coming out or it may jam up in the pipe stopping the flow. If it blocks the flow it is most likely to do so at a valve or other constriction in the pipe. 'Slush' ice in a pipe will in fact, behave much like frazil ice in a river in that it will freeze onto any cold object in the stream.

It has been suggested that, in the case of a heater failure in a circulating water system, maintaining a flow of even one or two feet per minute may prevent freezing of the system. The explanation for this observation may be in the fact that the flow of the water causes nucleation to occur with less supercooling than in the case of stagnant water. Thus only a small amount of 'slush' ice would be produced which if there was no major constriction in the flow system would probably not cause a flow stoppage. If a pipe does not become blocked during this initial stage of ice formation, an annulus of ice begins to form and no further supercooling occurs. Since it may be several days (for a 6" diameter pipe) before the annulus of ice grows to block the pipe, the margin of safety may thus be considerably lengthened by maintaining the circulation.

FROST PROTECTION FOR PIPING

As mentioned in the introduction, the best method of frost protection for water pipes is to avoid exposing them to a sub-freezing environment. For non-permafrost regions this would mean burying the pipes below the maximum depth of frost penetration. In a permafrost region where this is not possible some active method of freeze protection must be employed which continuously adds heat to the water system. There are number of methods by which this can be successfully

achieved in practice. However, since such systems cannot be made one hundred percent reliable, some thought should be given to methods whereby the possibility of damage caused by a freeze-up of the system might be minimized.

It was found that the dendritic ice formed because of supercooling in the water can cause blockage of a water pipe early in the freezing process. The time required for a pipe that is exposed to a cold environment to become blocked by dendritic ice is about a tenth of the time required for it to become blocked by the growth of a solid annulus of ice. Therefore, if dendritic ice growth could be avoided flow could be restarted in the pipe at a much later time with the prospect of melting out the ice that had grown in the pipe. There is also some evidence that a pipe with a large amount of dendritic growth in it will be more likely to burst when it freezes than one in which dendritic growth did not occur. The main emphasis of the work presently underway is therefore on exploring methods of minimizing the amount of dendritic ice growth in a pipe. This essentially means finding a method of nucleating ice growth when the supercooling in the bulk of the water in the water pipe is at or near the freezing point. One possible and very simple remedy that may be useful for an insulated pipe, would be to install a blanked off tee in the pipe with the blanked off end protruding outside the insulation. Such a device may trigger the nucleation of the ice with no supercooling occurring in the main pipe. It may also be possible to combine nucleation devices with the damage protection devices being developed by McFadden [8], thus also eliminating the possibility of damage occurring to pipes that had become frozen beyond the point at which flow could be restarted.

It is hoped that from the understanding of the pipe freezing mechanism that was gained in this study other ideas of possible methods of decreasing the problems caused by freezing pipes may come to light.

REFERENCES

1. R.J.E. Brown, Permafrost in Canada, University of Toronto Press, Toronto, 1970, Chap. 5.

2. J.W. Grainge, "Arctic Heated Pipe Water and Waste Water Systems", Water Research, Vol. 3, 1969, pp. 47-71.
3. K.A. Linell and G.H. Johnston "Engineering Design and Construction in Permafrost Regions", Second International Permafrost Conference, Yakutsk, 1973.
4. American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), Handbook of Fundamentals, p. 305.
5. R.R. Gilpin, "Cooling of a Horizontal Cylinder of Water Through its Maximum Density Point at 4°C ", Int. J. Heat Mass Transfer, Vol. 18, 1975, pp. 1307-1315.
6. T.E. Osterkamp, T. Ohtake and D.C. Warniment, "Detection of Airborne Ice Crystals near a Supercooled Stream", J. of Atm. Sc., Vol. 31, 1974, pp. 1464-1465.
7. N.E. Dorsey, "The Freezing of Supercooled Water", Trans. Am. Phil. Soc., Vol. 38, Part 3, 1948, pp. 245-325.
8. T. McFadden, "Freeze Damage Prevention in Utility Distribution Lines", Symposium on Utilities Distribution in Arctic Regions, Edmonton, Alberta, Canada, March, 1976.

FREEZE DAMAGE PREVENTION IN UTILITY DISTRIBUTION LINES

by

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INTRODUCTION

It has been theorized that freeze damage to pipes subjected to below freezing temperatures is the result of a buildup of hydraulic pressure. As freezing takes place the expansion of water changing to ice imposes an increasing pressure upon the unfrozen liquid remaining in the pipe. These pressures are transmitted by the liquid to the pipe as hydraulic forces which become extremely large (30,000 psi max) exceeding the burst strength of both metal and plastic pipes.

Dr. E. F. Rice, of the University of Alaska, suggested that the failure in a water pipe always occurs at the last point to freeze; that is, the point where the liquid, which is not frozen, has accumulated and is exerting the greatest pressure. Therefore, failure could be predicted, or positioned, merely by the addition of extra insulation at the desired point of failure. The extra insulation allows less heat loss and assures that these points will accumulate the pressurized unfrozen liquid and therefore be the points of failure.

To test this theory, McFadden and Rice (1972) conducted some preliminary experiments aimed at determining if the position of failure could be both predicted and controlled. These experiments demonstrated that, if a pipe was insulated over one specific area, this area would freeze later than the area adjacent and no strain could be detected in the portion of the pipe which froze first. All strain necessary to compensate for the increased volume of the frozen material inside the pipe was found in the area of the pipe covered by the greatest insulation.

Houk (1974) confirmed these observations and found further that he could attain a degree of control over the freeze damage by the use of insulation positioned in appropriate spots. This suggests that protection from freezing could be attained by providing pressure

relief at the last place to freeze between each pair of possible blockage sites. Such blockage sites were considered to be elbows in which the ice had firmly frozen, valves, or other fixtures past which the ice could not be forced. Figures 1, 2, and 3 show typical failures due to freezing.

TECHNICAL CONSIDERATIONS

Having found that the point of pressure buildup that causes freeze damage can be positioned by the addition of extra insulation, it is then only a matter of designing an appropriate means of pressure relief to eliminate the damage (Figure 4). The type of device needed will depend on the particular installation.

Several devices were examined for eliminating freeze damage. Chambers which relieve pressure by compressing air as pressure builds up, plugs which selectively fail under pressure, valves which open at a predetermined pressure and vent the line to a drain, and bellows which expand to compensate for the expansion, were considered. Table 1 lists various techniques considered.

Solenoid valve: The high pressure area is fitted with a solenoid valve which can be remotely triggered to open. Control can be as unsophisticated as a surface thermostat which activates the valve when the pipe surface reaches 0°C . More elaborate triggering could take the form of internal pressure transducers which activate at preset pressures. A latching check valve would constitute a simple extension of this type of device. This type of device has the advantage of draining the line when activated.

Air Chamber: A compressible air chamber such as a stand pipe can suffice providing it can be assured that it will not fill with water and that it contains sufficient volume to accommodate the expansion from freezing water without allowing damaging pressures to develop.

Expandable Bellows: Bellows of rubber and metal such as those used for misalignment can provide adequate volume increase to prevent pressures from reaching the failure stress of the pipe. They must be used frequently enough and be capable of adequate expansion. They are generally higher cost and do not allow the line to drain.

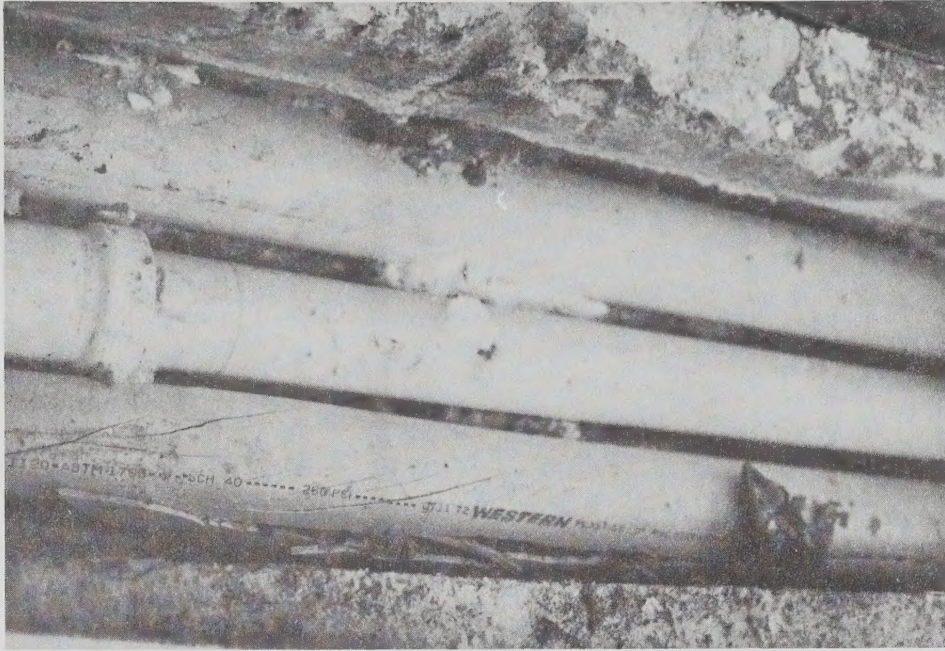


FIGURE 1. FREEZE DAMAGE TO WATER PIPES AT NOORVIK, ALASKA



FIGURE 2. FREEZE DAMAGE TO A HYDRANT AT MINTO, ALASKA

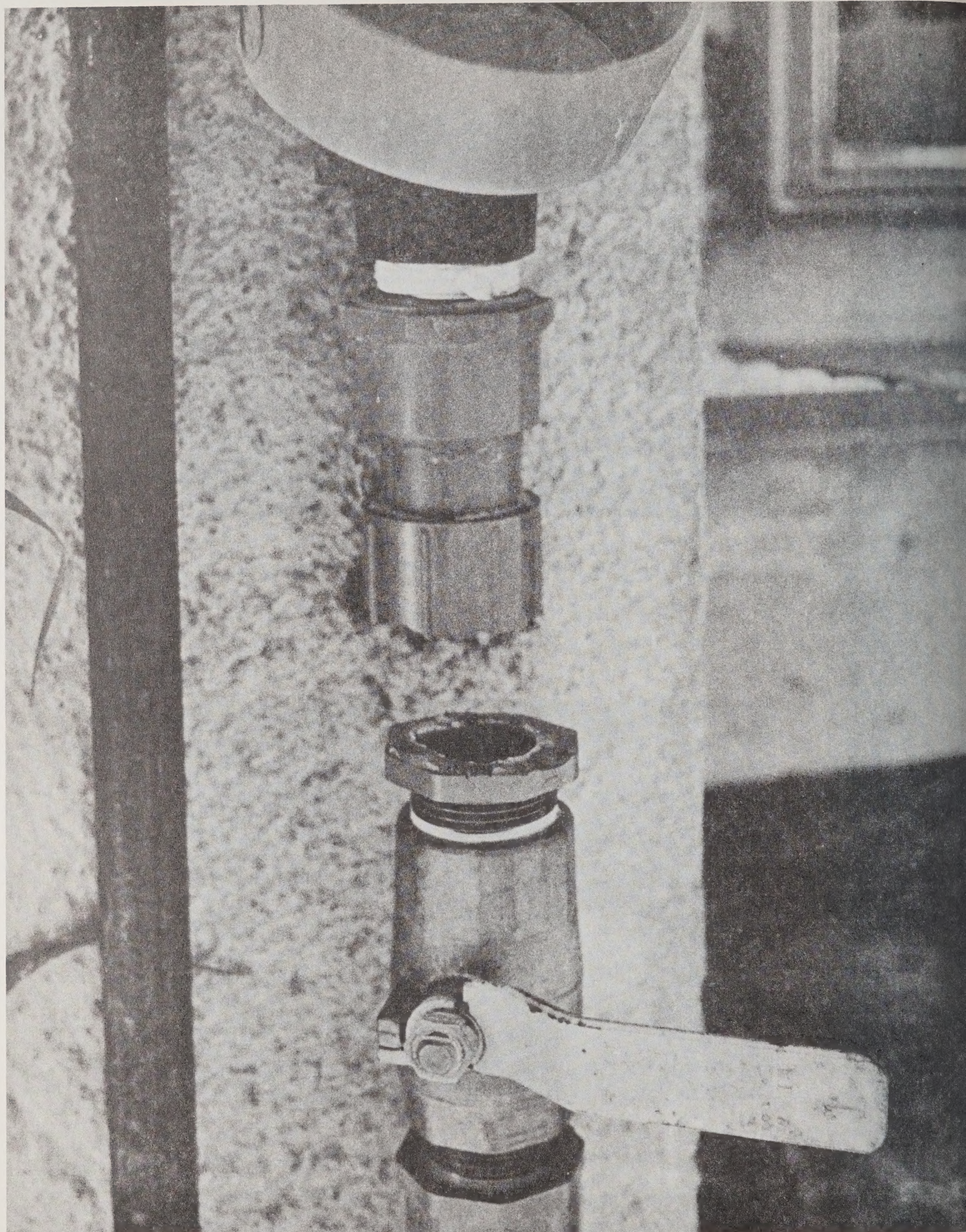


FIGURE 3. FREEZE DAMAGE TO PLASTIC PIPE FITTING

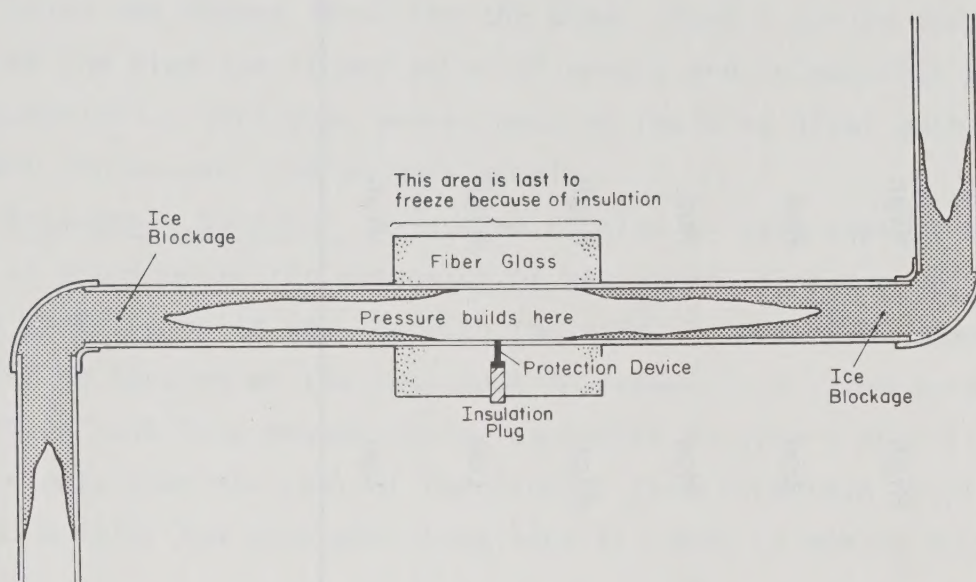


FIGURE 4. PRESSURE RELIEF AT THE POINT OF PRESSURE BUILDUP WILL ELIMINATE DAMAGE NORMALLY CAUSED BY FREEZING.

TABLE 1. PRESSURE RELIEF TECHNIQUES

Device/Technique	Remotely Reset	Requires Power	Drains Line	Cost	Reliability	Ease of Installation	Ease of Repair
Solenoid valve	Yes	Yes	Yes	High	High	M	VE
Air chamber	NA	No	No	Low	Mod	E	VE
Expandable bellows	NA	No	No	Mod	Mod	E	VE
Friable section	No	No	Yes	High	High	VE	D
Bursting diaphragm	No	No	Yes	Low	High	E	E
Expandable section	NA	No	No	Low	High	E	VE

E = Easy
 M = Moderately difficult
 D = Difficult
 VE = Very Easy

Friable Section: A section of pipe which will fail at significantly lower stress than the main line can be used to protect the rest of the line. This section can be placed at a convenient location for the failure, such as a position that is easily repaired or will not be damaged by the water draining from the line.

Bursting Diaphragm: A diaphragm can be designed to fail at pressures below the damage level for the pipe. Such a device can be installed in the pipeline at any point of danger and in quantity should be very economical. This type device must be replaced after each failure, but replacement can be very simple.

Expandable Section: A section of pipe or tube capable of expanding to accommodate the expansion of the entire line can be used to prevent pressure build up. As with the other methods the expandable section must be located at the last spot to freeze (i.e., the location of the section must have enough extra insulation to assure that it loses heat more slowly than the rest of the line). This technique is primarily of value on smaller low pressure lines such as found in mobile homes, etc.

EXPERIMENTAL RESULTS

At the present time the most extensive tests have been made using the bursting diaphragm. The diaphragm device tested was designed by Fred Reif of the Alaska Native Health Service. The device consists of standard pipe fittings, a thin metal diaphragm and a fabricated cap (Figures 5 and 6). The diaphragm was designed to fail at a pressure of 250 psi. This method has the advantage that once pressure has reached this level, the line is then opened and remaining liquid drains out, leaving an annular space inside the line through which thawing equipment can be inserted to melt the remaining ice in the line.

Several diaphragm materials were tested, including neoprene, brass, copper, aluminium, polyethylene and mylar. Brass shimstock, 0.003 inches thick, was found to give consistent failures in the pressure range desired.

The protection device using a brass diaphragm was then installed on a section of 4 inch diameter water pipe. The pipe was then insulated

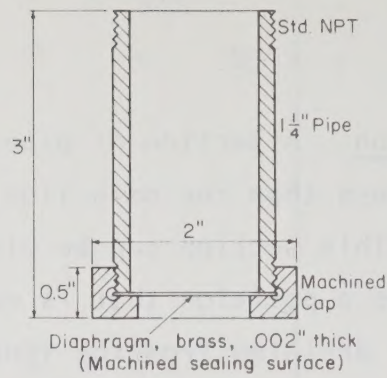


FIGURE 5. BURSTING DIAPHRAGM PROTECTION DEVICE

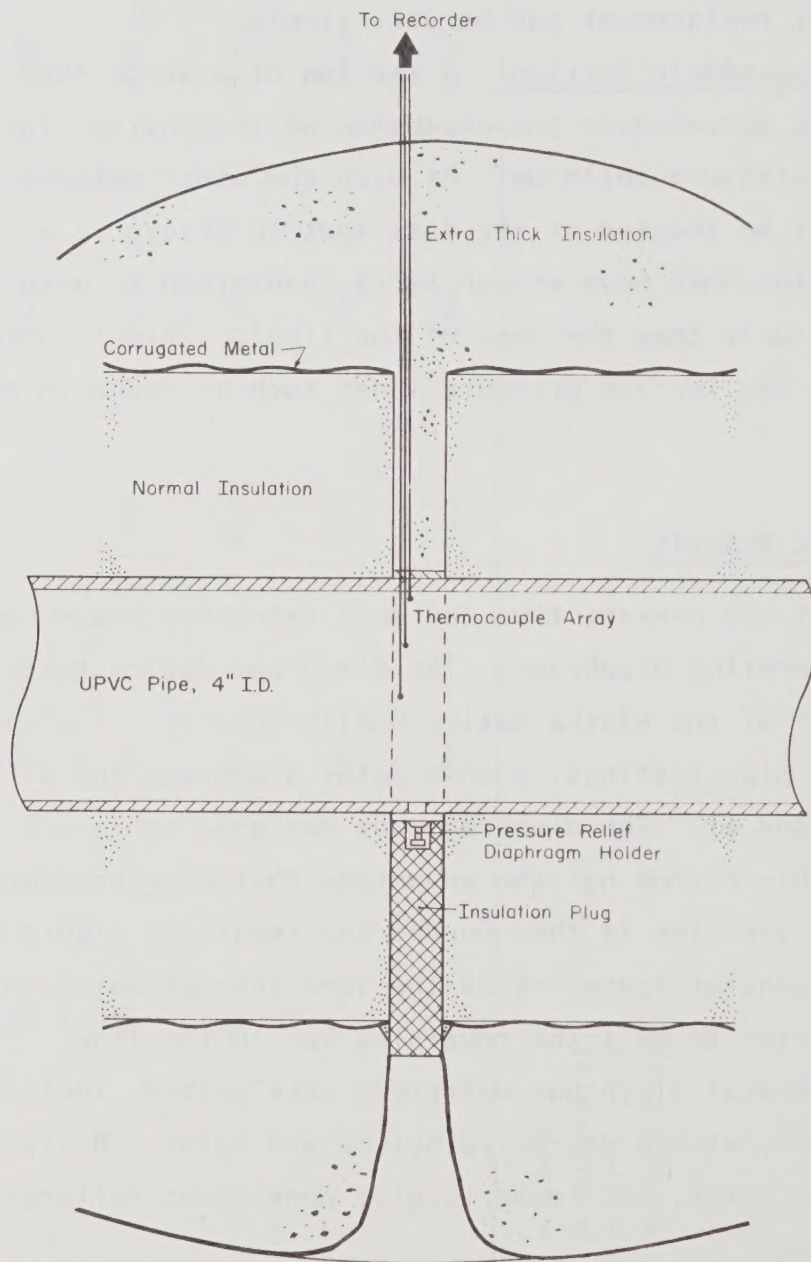


FIGURE 6. INSTRUMENTATION FOR FREEZE CYCLE

with 3 inches of extra fiberglass insulation in the area where the protection device was installed, to assure that this would be the area where pressure would be developed. The pipe was subjected to a cold room temperature of -20°C to -40°C . Failure of the diaphragm protected the pipe from damage in each freeze cycle. After the third experiment, the pipe was pressurized to 250 psi to check for damage. None was found.

An experiment was performed on an 80 foot length of pipe connected to a 10 foot length by a right angle elbow. One pressure release device was installed in the middle of the pipe. Pressure relief in the area of extra insulation prevented damage to the rest of the pipe. However, the insulation was improperly placed and did not prevent ice formation in the pressure relief device. This ice in turn plugged the relief port and the service saddle failed to accomplish the needed relief. Although the pipe was damaged, it was confined to the area of extra insulation. This further supports the concept that the position of failure due to freezing can be controlled.

The expandable section concept was tested on smaller pipe of the size normally found in household plumbing. A short three inch section of heavy wall vinyl tubing was placed between straight sections of three-quarter inch diameter copper tubing. Each section of vinyl tubing was then insulated to slow the freezing process in that area and the system was frozen. The copper pipe was carefully checked for strain by measuring the diameter before and after freezing. No strain was detectable in the metal section that froze first.

The elastic sections however exhibited considerably more than 10% expansion and obviously had accommodated the expansion from the connecting copper pipe. In each case the copper was undamaged, and after thawing, the vinyl sections were still leak tight, although a bit stretched.

The main disadvantage of this method lies in the creep characteristics of the elastomer. Since water systems are expected to have lifetimes of many tens of years (sometimes hundreds of years) every member of the system must have a similar lifetime under normal load pressures. Because of the creep rate of most elastomers, delayed failure at normal pressures can result. Much more work must be done in this

problem area. Actual failure loads after lengthy exposures to normal pressures must be determined. Material specifications must be set up and fatigue life measured. Materials whose failure rate is acceptable will be found and design criteria established.

Development of reliable systems using several of the methods discussed will be the goal of continuing research in this field.

CONCLUSIONS

The above experiments, while limited in number, suggest that freeze damage can be reduced or completely eliminated by the use of the relatively inexpensive freeze protection devices listed in Table 1. In quantity they should be relatively inexpensive. Installation of the device in the line is simple and should require only standard tools and plumbing fixtures and the additional insulation to position the location of pressure buildup.

Failure of the diaphragm device was found to protect the plastic pipe from damage in each case. More extensive testing is obviously needed to determine design flaws, to assure that all possible piping configurations are protected and to determine the optimum spacing of the diaphragm protection devices.

The expandable sections have the advantage of remaining intact throughout the freeze cycle and do not need any repair or replacement. They are inexpensive and easy to supply; however, much more testing is needed to determine their reliability and fatigue life.

If it is impractical or economically unfeasible to protect the line with one of the devices discussed above, then the failure can be positioned with insulation so that it is either easily repaired, or at least causes the minimum amount of damage.

It must be remembered that every vulnerable area must be protected. Each elbow and valve or fitting must be examined to determine its potential for causing a blockage which will result in a pressure buildup, and line failure.

Overall, considerable savings in installation and repair could be achieved by introducing protection devices into water and sewage distribution lines, as well as household plumbing systems.

REFERENCES

Houk, J., 1974, Freeze damage in water containers, Northern Engineer
Geophysical Institute, University of Alaska, Fairbanks, Alaska.

Rice, E.F., 1972, Personal correspondence, Fairbanks, Alaska.

Streeter, 1958, Fluid Mechanics, McGraw - Hill, New York.

SESSION III

DESIGN GUIDELINES FOR PIPING SYSTEMS

PANEL DISCUSSION

DESIGN GUIDELINES FOR PIPING SYSTEMS

SPEAKER - I. Drinnan, Department of Public Works Government of the Northwest Territories, Yellowknife.

Utilities in arctic and sub-arctic regions are still in their infancy, and guidelines for their design cannot reasonably be as restrictive at this time as those reflected in the codes and standards of our various regulatory authorities. These authorities have been open to argument for relaxation or at least liberal interpretation of code requirements, usually with satisfactory results. Recently, however, there have been indications of a trend towards tighter control, and there is a need to establish consensus on as many facets of system design as possible, as soon as possible, to be effective in tailoring regulations for northern environment.

Existing and proposed utility systems evidence differences of opinion, e.g. above vs below ground systems, utilidor vs individual pipes, metals vs plastic, some of which may never be satisfactorily resolved. Current planning, at least as it relates to routing and sizing of water mains, may be erroneous in concept. The implications of some of the controversies are potentially serious, and there is an urgent requirement for dialogue exploring their validity.

Concepts based on highly frost susceptible soils should not be exported into areas with less critical soil conditions, e.g. in the N.W.T., utilidors that were right for the Mackenzie Valley have been recreated in essentially identical form in eastern arctic communities, without significant regard for considerably more stable soil conditions representative of these regions. Not only the concept, but also the terminology has been transferred with such influence that it is today well nigh impossible to eliminate the word 'utilidor' from discussions of northern municipal piping systems.

There are now, and always will be, situations where above ground installations are practical necessities; however, we should question the assumption that the utilidor is a necessary part of such a system. Such

installations are (or should be) high-technology solutions to specific problems, and they should be limited in application.

The design of utilidors tends to be highly individualistic and full of innovative detail. A certain amount of experimentation is, despite attendant risks, of ultimate benefit to all. However, the introduction of too many innovative ideas at one time tends to obscure the observation of the results and to reduce their value. It must also be recognized that innovation can be costly.

Conventional systems are, however imperfect they may be, at least well understood at all levels of involvement. Contractors are familiar with them, component parts are readily available; so costs are fairly predictable. Operators, most of whom obtain their training 'outside' (in urban areas of the south), readily accept them. Where conventional features are not appropriate to northern conditions, they can, and should, be modified; the temptation to discard them in favour of unproven alternatives should be resisted, at least until the full understanding and cooperation of the end user is assured.

It is somewhat arrogant to assume that one can start from scratch and come up with the 'perfect' system. Familiarity with tried and trusted methods is more likely to produce a working system than pure design, no matter how excellent the latter. Once again, this should not be construed as an argument against innovation, but rather as a plea for the application of innovative ideas and concepts only on the basis of deficiency in convention, and only after exploratory discourse with administrators, contractors, operators, and all those involved in practical systems.

It cannot be overstressed that, however excellent the engineering, however competent the fabrication and installation, however complete the satisfaction of codes, regulations, standards and guidelines, no piping system will meet expectations unless its operator believes in it. This would be true anywhere, but it is especially true of northern communities where operations and maintenance personnel have, through isolation, developed habitual self-reliance and associated disregard for imported solutions to their problems. In some way, as yet undefined, design guidelines should address themselves to establishing end-user confidence.

Some typical considerations given to design, installation and operation of municipal systems are appended.

BASIC GOALS

The basic goals to be met by piping systems may, bearing budget restrictions in mind, be expressed in either of two ways:

- a) to provide adequate sanitary and fire protection for the maximum population for the minimum cost as reasonably consistent with reliability and operations/maintenance considerations, or
- b) to provide excellent sanitary and fire protection for the population.

An example of the latter being preferred over the former is in the current lobby for secondary sewage treatment in small, remote settlements. These tend to be fairly costly propositions that serve to reduce the funding available for the more fundamental goals of supply and distribution of fresh water and for the sanitary collection of wastes. The desirability of high quality treatment is self evident, but the priority being assigned to it in influential quarters appears unbalanced.

CODE REQUIREMENTS

Although the public health standards and regulations established and proven in the south, especially those of the Prairie Provinces, have applicability in sub-arctic and even arctic systems, they are not sufficient. Effluent quality standards that are essential minima in Toronto may be impracticable in Grise Fjord. The cement pipe that performs so excellently underground in Lethbridge may not contain wastewaters so effectively in "utilidor" applications.

COSTS

At the present time capital costs for providing the minimum standards of piped water, sewage collection and treatment are around \$4,000 per capita. Higher standards can be obtained, but unless budgets are increased a lesser number would be served. Conversely, it is

possible to provide for more people at a reduced level of service or construction quality, or both. Only fundamental re-examination of the basic needs and of the practical realities could possibly produce a more cost-effective servicing program.

MATERIALS

Arctic utility systems are being installed today for less cost than a decade ago, size for size. This is being accomplished largely through innovative applications of old and new materials, like thinwall metallics and plastics in combination with foam insulations. Some materials, like asbestos-cement and PVC pipes and polyurethane insulations have been shown to have some unanticipated problems and limitations, but remain in effective if restricted use. Other miracle products have disappeared in time, leaving devastated applications in their wake. Municipal designers must be on guard against over-zealous salesmen with glamorous but unproven offerings, while remaining receptive to good ideas that represent dollar value.

SERVICES & APPURTENANCES

All that has been said about pipes applies to building services and appurtenances, but all the more so because these are the natural weak points in any system the points at which the system comes in contact with the hazards of climate and human activity. No system design should proceed beyond the conceptual stage without the fullest consideration being given to its practicality for services and appurtenances, and these should be the first details decided upon. Since it is these items that the system operator will attend to in the normal course of his duties, his interests are as important as the requirements of health and safety regulations and must be given the proper weight and priority.

DESIGN CRITERIA

1. Design in accordance with current codes and practices, unless good cause for change can be demonstrated to the satisfaction of regulatory authorities.

2. Avoid "specials" particularly where similar results can be obtained with familiar alternatives.
3. Maintain simplicity, but where complexities are unavoidable centralize them, and minimize field-located operations and maintenance items.
4. Avoid conventional "minimum" grades on gravity sewers, especially in suspect soils.
5. Employ freeze preventive measures, but also provide appropriate means to facilitate thaw.
6. All else being equal, select on the basis of progressive development, e.g. if selection of sewer material comes down to clay vs AC, use AC because of its greater possibilities in further applications.
7. Do not hesitate to borrow ideas from other engineers - the more similarity the better.

PANEL DISCUSSION (CONT'D)

SPEAKER - J. Sargent, Alaska Department of Environmental Conservation, Juneau

It is interesting that Ian has raise some of the very issues that have come up between the Department of Environmental Conservation in Alaska, and Alaska's Department of Public Works. We should have a lively conversation here.

The Village Safe Water (VSW) program is new in Alaska. To understand our feelings about pipeline construction, you need to know a little about what a Village Safe Water facility is. The Village Safe Water Act says that the State of Alaska is authorized to construct what is called a central sanitation facility for small communities in rural Alaska. By that we mean a place where people can come to get the sanitation services as opposed to having them distributed to the individual homes. The concept of a central facility as opposed to service to individual homes has already been debated at this conference. We erect a building that has a place for people to come and get water, and a place for people to dump wastes such as garbage and honey buckets. The facility can also include laundry and bathing facilities. You can see that pipelines are not a big issue with us, except to the extent they are needed to get raw water into the facility and to carry waste effluent out.

Pipelines of any length are not involved in VSW facilities and our projects are usually in small, remote villages. Two general rules that we have arrived at - and again remember they are in the context of Village Safe Water experience - are 1) keep them short, and 2) keep them above the ground. I will relate some our experiences which prompted those rules.

First of all let me start with the raw water intake line. We had three cases of buried raw water intake lines. Two of those lines were steel, with insulation and heat tapes. The third line was polyethylene pipe laid inside what we call Arctic Conduit, along with a heat tape. I'm sure you will hear more about Arctic Conduit from Bill Ryan.

It is a pipe that the Public Health Service uses a lot, composed of plastic pipe inside a urethane doughnut, with an aluminum sheath around the outside. Of the three buried raw water intake lines, one of them failed within a few months after we started using it, and two of them failed just as the contractor was finishing construction. There were all kinds of factors contributing to these failures. But I think they illustrate the point that in designing and building pipelines the normal operating situation is not the limiting condition. You can do the heat loss calculations and design the pipeline for the normal operating situation. But the thing that hurts you is the exception - the conditions that disrupt normal operation and cause a pipeline to fail.

When something happens to a pipe buried in the ground, one of the main problems is diagnosis. At typical VSW sites it is very cold in winter, and problems usually occur when the ground is frozen. Hence it is very difficult to get to the pipe, so we don't know in all cases just what is wrong. Many times all we can tell for sure is that water is not coming through the pipe. And even if we could diagnose the problem, repair is often impossible until the ground thaws.

In the case where we had the polyethelene pipe with a heat tape inside the Arctic Conduit, we were in a better position to make repairs without digging up the pipe. But in the cases where the insulated and heat taped steel pipe was just buried directly into the ground rather than inside another conduit, we had real problems. In fact we had to abandon one of those lines.

At VSW sites there usually is no equipment available to us, we don't have the kinds of facilities that justify bringing in big equipment, and we are in places where big equipment just doesn't last very long anyway. Since we lack the capacity to readily dig down to pipelines, we choose to have them accessible at the ground surface.

At one village we have a polyethelene water line in a utilidor being heated with glycol. It has worked well so far, but the glycol system is, of course, expensive.

In addition to the raw water pipelines, we have relatively short sewage effluent lines. At five of our six operating facilities the effluent lines are above ground. One is wood stave pipe laid on

the ground, one is wood stave pipe on piles, and three are Arctic Conduit suspended from piles. All but the wood stave line on the piles have heat tapes.

One of our waste effluent lines is buried. Soil conditions at that site are such that we could use an underground leach field for secondary effluent. We haven't had any problems with the line yet, but we have only been in operation for about a month. We have our fingers crossed.

To gain a wide range of ideas on how VSW facilities might be built, we have involved several consultants in design of our various projects. It seems that nowhere are design ideas so varied and sometimes conflicting as in connection with arctic pipelines. One designer might recommend a certain kind of heat tape with a certain kind of pipe, while the designer next door on the next project will say: "you should never use those two materials together."

My point is that there are lots of different kinds of materials, and there are lots of different combinations of ways to put arctic utility conduits together. It is necessary to study each installation individually. Each pipeline installation has its own unique features and peculiarities. And remember, it is not usually under normal operating conditions that failures occur. Pipeline failures are frequently caused by unforeseen events that disrupt normal operation.

PANEL DISCUSSION (CONT'D)

SPEAKER - William L. Ryan, Sanitation Facilities Construction Branch,
Indian Health Service, Anchorage, Alaska

INTRODUCTION

The Indian Health Service (IHS), Sanitation Facilities Construction Branch, constructs sanitation facilities such as water sources and treatment, water distribution and sewage collection systems, sewage treatment, and refuse collection and disposal with the objective of improving the health of the Alaskan Indians and Eskimos. There are some 60,000 Indians and Eskimos spread throughout the State of Alaska living in about 220 communities.

The facilities installed must be operated and maintained by the community for which they are constructed after completion and the operators are trained. Thus IHS, the community, the Regional Native Association, and other possible customers for the services must consider all the alternatives for a given community and decide what type of facilities will give them the most health improvement and still be within their capability to operate and maintain. This is an important and difficult decision to make. The Canadian government bases this decision almost entirely on population but IHS has found that this doesn't always hold.

IHS is not restricted to any particular type or complexity of facility. Small, disorganized villages cannot take on the responsibility of operating and maintaining a piped distribution and collection system and if such facilities are constructed they will fall into disrepair. In these cases, the most practicable solution may be a simple watering point providing safe water from which individuals haul their water. However, IHS has constructed complete piped distribution and collection systems in small communities that have successfully taken on the responsibility of operation and maintenance. If there is one common denominator that can be singled out to indicate whether or not a community will succeed in operating and maintaining the facilities constructed, it seems to be an individual (or group) in the community that will take a

sincere interest in seeing that the facilities are taken care of. Also, his employment and requests must have the backing of the community leaders.

Ten to twelve projects per year at a total of about 10 to 12 million dollars, are initiated by IHS, the actual number depending on congressional appropriations and the cost of the projects. In Arctic Alaska it takes two and sometimes three construction seasons to complete a project so there are about 30 in different stages of planning and construction at any one time. Some projects are contracted (engineering and/or design) but most are constructed force account with IHS engineers and foremen directing local native crews. There are few engineering firms familiar with "bush" conditions and "outside" contractors usually bring in their own more highly trained crews rather than utilize local workers. Because of these factors, and others, we use our own staff depending on the workload.

IHS also provides technical help to communities when requested. This help often takes the form of the preliminary engineering report required for the community to apply for sanitation facility or other construction funds from another Federal or State agency.

There are over 70 communities that have applied for IHS help with sanitation facilities that have not received a project. As they apply they are placed on a priority list for later funding according to the following four main criteria:

1. The health need in the community (i.e., the number and severity of environmentally related disease outbreaks).
2. The communities ability and willingness to operate and maintain the facilities upon completion of construction.
3. The ability and willingness of the community to participate in the construction such as loaning equipment or donating gravel, labor, etc. to the project.
4. The engineering feasibility of the project. This would include the cost per living unit to construct the needed facilities.

OPERATION AND MAINTENANCE

As discussed before, the single largest problem is designing and constructing facilities that are within the communities' ability to operate and maintain. IHS does not have funds for operation and maintenance so, these costs must be borne by the users. There are state revenue sharing funds for communities providing sewage treatment and fire fighting facilities, but these funds are very limited and are not significant in comparison to the funds needed to operate the facilities. In the construction of facilities, IHS will design in lower operating and maintenance costs even at the expense of higher initial construction costs because the success of the facility hinges on the community keeping it operating.

Other recent obstacles to the construction of facilities which the individual communities can operate and maintain are the Water Pollution Control Act (PL 92-500) and the Safe Water Act (PL 93-523). PL 92-500 applies sewage treatment requirements designed to clean up and prevent pollution in rivers in heavily populated areas across the board to remote installations where they are not practicable. IHS, in its goal of improving the health of the native people, feels that it is a significant improvement if the sewage can be collected from around the houses in a small village and deposited in a pond away from the village or even into a river. The State Department of Environmental Conservation (DEC) and/or the Environmental Protection Agency (EPA) take the position that unless the provisions of PL 92-500 can be met (at least "secondary treatment") in a remote native village, nothing should be done. They do not consider a facultative sewage lagoon as providing "secondary treatment" in arctic areas, but do not have an alternative to offer which is within the capability of the villages to operate and maintain. IHS feels that a lagoon which will usually give an average of 60 to 70 percent removals all of the time with little maintenance is a much better solution than a more conventional sewage treatment plant which may produce 90 percent removals for less than half of the time. In fact, proper operation and maintenance is probably unattainable half the time in remote communities. As an example, DEC and EPA have also taken the stand that sanitary landfills or trench type burying are not

satisfactory in permafrost areas. This leaves hauling the refuse away or incinerating it as about the only acceptable solutions. Both of these methods are extremely costly and are not a logical solution to refuse disposal in a native village. A village cannot pay 40¢ to \$1.30 a gallon for fuel oil to burn refuse or sewage. Several villages and larger cities in Alaska sport "white elephant" sewage treatment plants and incinerators, constructed to meet federal and state discharge requirements. These facilities operated once or twice, usually until the first electrical or fuel bill came in, and then were bypassed and left to rust. IHS has taken the position that if DEC and EPA are going to require these levels of treatment, they must also guarantee the needed financial aid to operate them and enforce the discharge limits that they place on the operation of the plants. Under these conditions IHS can and will construct the treatment facilities necessary to meet their requirements.

The restriction of not allowing primary treatment and deep water discharge by ocean outfall in lieu of secondary treatment imposes a financial burden on coastal communities. There are several large cities (including Anchorage) fighting this restriction. As an example, IHS recently analyzed the difference in costs to the village of Hydaburg in southeast Alaska. Primary treatment (including removal of floatables and settleables to a landfill) and discharge through an ocean outfall would cost about \$10 per family per month less to operate and maintain than a conventional extended aeration sewage treatment plant that would provide secondary treatment. When one considers that Hydaburg has had problems operating their present water and sewage system with costs of less than \$5 per family per month, the success of a secondary treatment plant without an operational subsidy can be easily predicted. Raw sewage has been discharged at low, low-tide through three outfalls at Hydaburg for over 5 years with no signs of pollution on the beaches or in the surrounding waters. There are considerable water exchanges and high dilution factors because of the extreme tides and sparse population along most of the southeast coast of Alaska.

The problems and expenses that will be initiated by the Safe Water Act (PL 93-523) are speculative at this time, but they will likely be extreme for a small community. IHS installs chlorination and fluoride

saturators on all projects. There are numerous communities where iron, color, and/or taste removal is necessary. The first part of any water source that falls into disrepair is the chlorinator. If these small, relatively simple, pumps are not maintained, what is the chance of the considerably more sophisticated treatment equipment which will have to be installed to satisfy PL 93-523 being maintained?

BURIED OR SURFACE LINES

One of the primary design factors which must be considered in designing water distribution and sewage collection lines in a community is whether to bury the pipelines or place them on the surface. This decision must be based on several conditions:

1. the frost susceptibility of the soil;
2. spacing of the buildings to be served and the traffic pattern throughout the community;
3. vulnerability of the above ground lines to vandalism, etc.
4. ease of maintenance during winter;
5. allowable heat losses and cost of heat;
6. necessity of holding grades;
7. whether or not central heating will be included in the project; and,
8. whether or not gravel is available for bedding of the lines.

If the soil is highly frost susceptible there will be problems if pipelines or electrical lines are buried, etc. The Corps of Engineers uses the definition of more than 3 percent passing the #200 sieve as a frost susceptible soil. IHS has buried water and sewer lines in soils worse than this with no major problems, but has also had some problems in soil with fewer fines. The moisture content of the soil is an important factor. Short of lengthy tests we know of no definite values of moisture content and percent fines which could be given as a "go" or "no go" limit for burying facilities. An important consideration in this decision should be whether or not the ground cracks in tension late in the winter. These tension cracks can be many feet long and up to 3 or 4 inches wide. If the soil is frozen tightly around the buried

line, this much shrinkage can pull it apart. Also, definitely avoid ice wedge or frost polygon areas and areas having thick ice lenses.

Surface lines or utilidors can cause traffic (foot and vehicular) circulation problems in a community. A small group of buildings can usually be connected with surface lines without serious circulation problems. If utilidors are used and the structures are spaced out over a considerable distance, the costs can be astronomical. Utilidors can cost anywhere between \$100 and \$600 per foot depending on complexity and what they include. To make utilidors an economical alternative, the spacing of buildings served must be as small as possible.

One of the main problems encountered with above ground pipes or utilidors is vandalism and damage by vehicles. The utilidor should be designed to withstand people walking along them. In communities in extremely wet muskeg areas, the utilidors can be designed to also serve as walkways or boardwalks thus serving two purposes and becoming an important asset to the community. IHS has done this in Noorvik, Alaska.

The primary drawback to buried pipelines is the difficulty in making repairs when the ground is frozen. When a leak occurs it can take a day of hard work to just excavate a few feet to the line for repairs. Only large backhoes will dig frozen ground. IHS has found one of the most successful methods of excavating the frozen ground is to break it up with a gas or air operated jackhammer with a pavement breaker bit. Also if there is a frozen crust on the ground, it is often hard to locate a leak because the water can travel beneath the frozen crust, breaking through at a tension crack or weak point a considerable distance from the actual break. Tracing the surfacing water back to the actual break can be a time consuming and expensive problem. Surface lines, on the other hand, can be repaired in almost any weather.

Heat losses from a pipe or utilidor are directly related to the difference in temperature between the inside and outside. Heat losses in a surface facility are considerably higher than buried lines because they are subject to winter air temperatures of down to -50° F. While lines buried only a couple feet are seldom subjected to temperatures lower than $+10^{\circ}$ F. Where operational costs are a problem, this can be a significant difference in costs for a community.

If it is necessary to hold grades such as with gravity sewer lines, it will be necessary to have lines above, on, and buried in an installation, or it will be necessary to place them on piling varying distances off the ground.

Another solution we have used to try and utilize the good points of both above and below ground lines is to place the lines at the surface with the top of the installed pipe flush with or slightly below the ground surface.

As mentioned before, the two major factors which will probably determine the type of installation are the availability of gravel and the frost susceptibility of the soil.

SERVICE LINES

The service lines extending from the main distribution lines in the street to the building served are the largest operation and maintenance problems in an arctic water system.

The design developed by IHS combines the two 3/4" copper service lines with a heating tape and an insulated thaw wire inside the standard 4" arctic conduit (See Figures 1 & 2). The two copper lines are necessary so the water can be circulated from the main to the house in one and then from the house back to the main in the other. This circulation is provided by small circulating pumps and/or pitorifices using the velocity in the main.

If a service line freezes, the first attempt to thaw it is by using the heat tape. If the heat tape is not operable or will not thaw the lines the next step is to thaw the lines using an electrical thawing machine and the thaw wire. This method can cause electrolytic corrosion of the lines which will probably mean they will have to be replaced after several thawing cycles.

A big problem has been finding a reliable heat tape and thermostat. IHS is presently testing several different heat tapes or traces to determine which will provide the most economical and reliable service. It appears, at this point, that the best type is one having heat output proportional to the temperature at any location along its length (Type "V" on Figure 3), i.e., the lower the temperature the more BTU's per foot

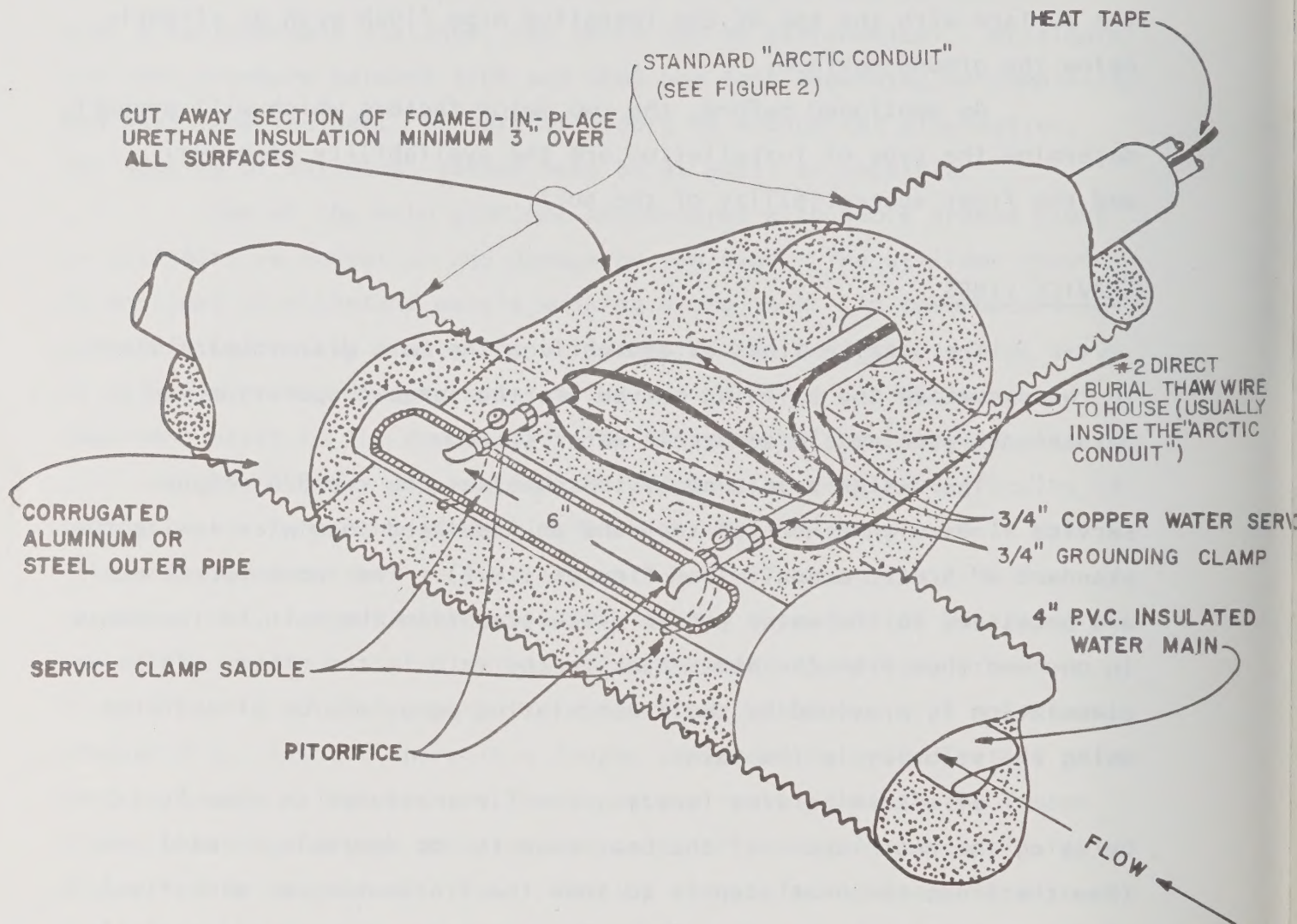
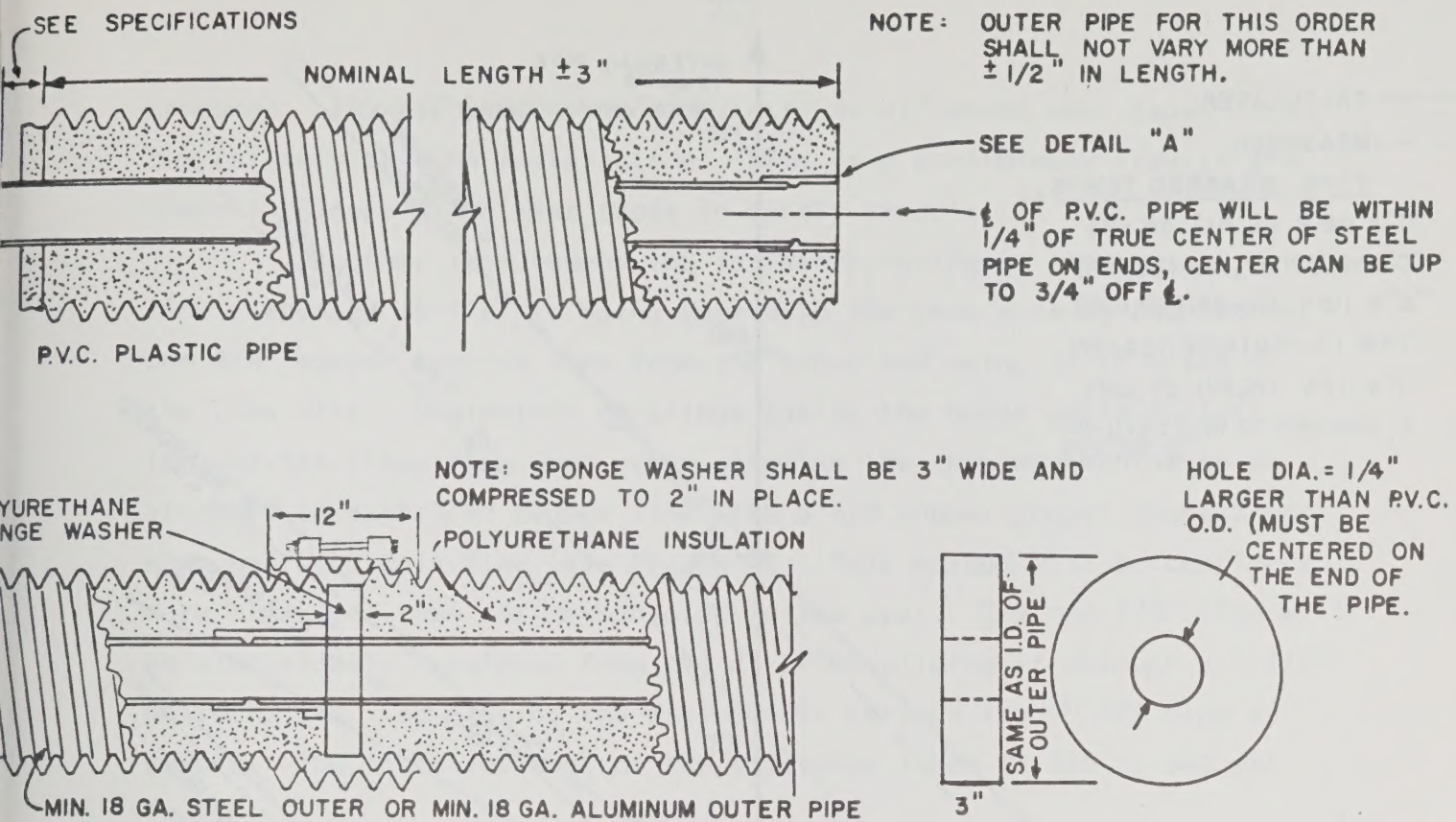


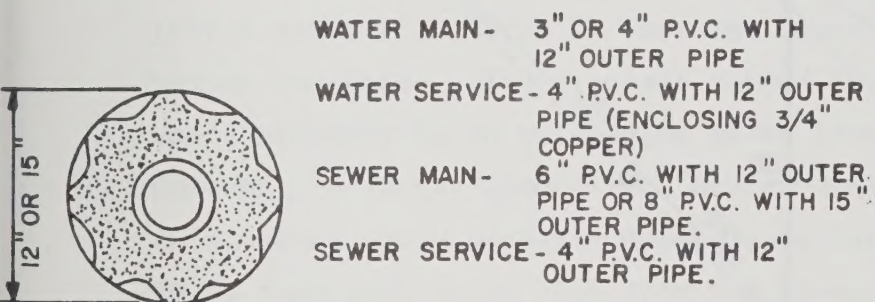
FIGURE 1. INDIAN HEALTH SERVICE - SERVICE LINE DETAIL



JOINING AND CLAMPING

POLYURETHANE SPONGE WASHER

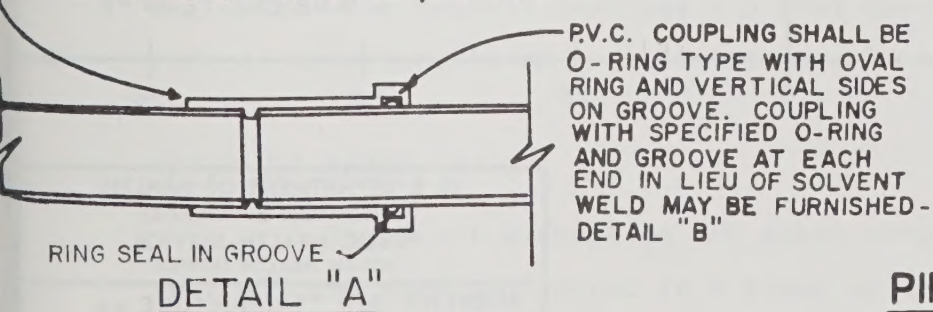
(TO BE SUPPLIED BY OTHERS)



PIPE END VIEW

CLAMP END VIEW

SOLVENT WELDED BELL TO P.V.C. PIPE



1/2 x 6 1/2" BOLT
W/2-NUTS

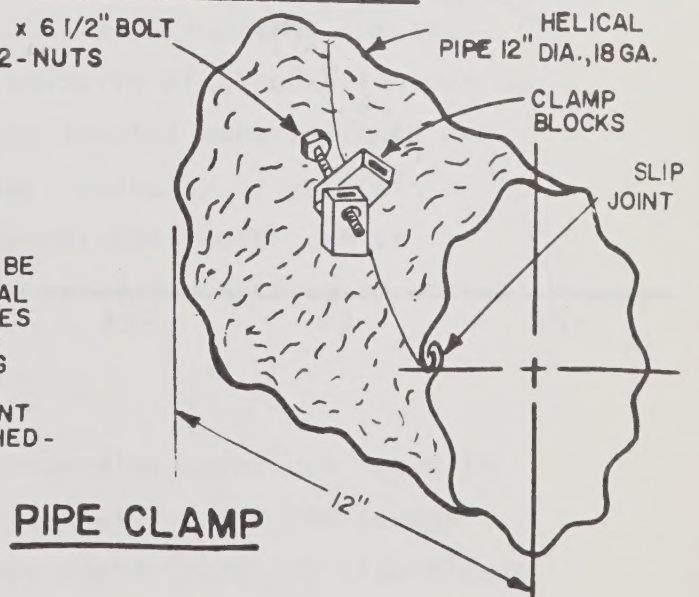


FIGURE 2. INDIAN HEALTH SERVICE - "ARCTIC CONDUIT"

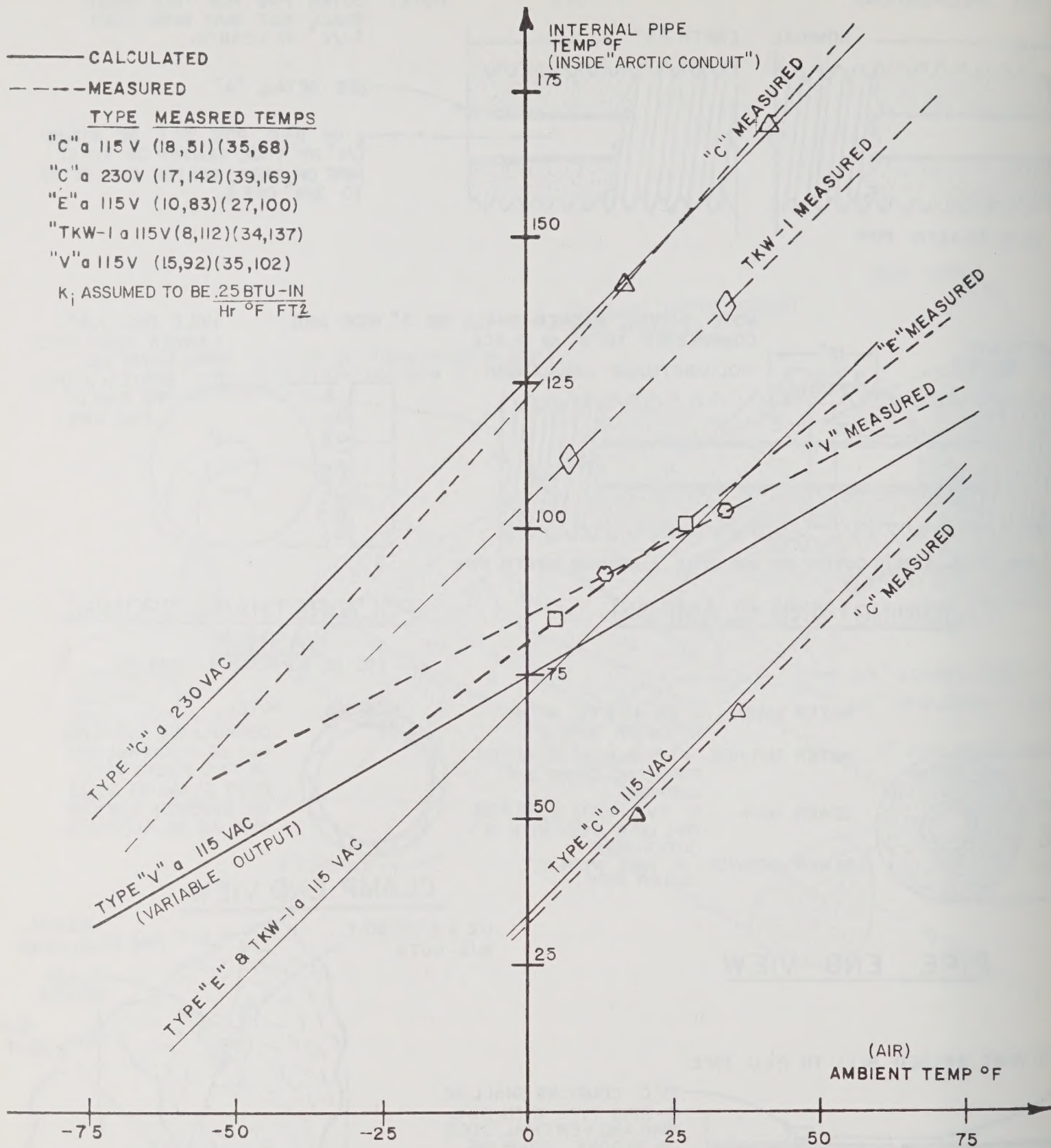


FIGURE 3. HEAT TAPE TESTS

U. S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE PUBLIC HEALTH SERVICE INDIAN HEALTH SERVICE	
AMBIENT AIR TEMPERATURE vs INTERNAL PIPE TEMPERATURE PROJECT NO.	
Drawn By:	
Date:	
Sanitation Facilities Construction Branch Office of Environmental Health Alaska Native Health Area Office	

produced. IHS has been conducting tests of different heat tapes in a typical service line installation. Some very preliminary results are shown in Figure 3 for heat tapes in arctic conduit.

Another improvement IHS is incorporating in the typical service line presented earlier is doing away with the thaw wire by insulating one 3/4" copper service line from the other and using it in place of the thaw wire. Dielectric couplings inside the house would isolate the service lines from each other allowing the thawing machine to be attached to each 3/4" copper line with a 4/0 copper jumper connecting them near the main line (See Figure 4). This method will be considerably more efficient than the method used in the past. The one 3/4" line will be electrically insulated from the other by sliding it through a 1-1/2" polyethelene line placing the entire unit through the 4" PVC pipe as before. The installed cost of these service lines is \$30 to \$40 per foot.

IHS is also considering a "conventional" design which would allow circulation through all lines and completely eliminate service lines. This will require the main line be extended to each house with just a short riser from it into the house plumbing directly beneath or beside the house. The simplest method to do this in a small community would probably be to extend the mains from house to house directly. However, in larger communities having dedicated street ROW'S, etc., this method would probably necessitate laying the mains in street ROW's then continuing them from the street into the houses and back in the same trench (all main line pipe). This will increase the total length of pipe in most instances, but the velocity of circulation can be reduced (to less than 1 ft/sec. depending on length) because there are no pitorifices, etc. that require a 2 ft/sec. velocity or greater in the main. The overall headloss and thus operational costs can be reduced considerably at a small increase in initial construction costs.

WATER USE RATES

The first assumption IHS makes concerning water use rates is that all the water delivered in a piped system will return as sewage. This was proven a reliable assumption except where there are significant leaks in the water system.

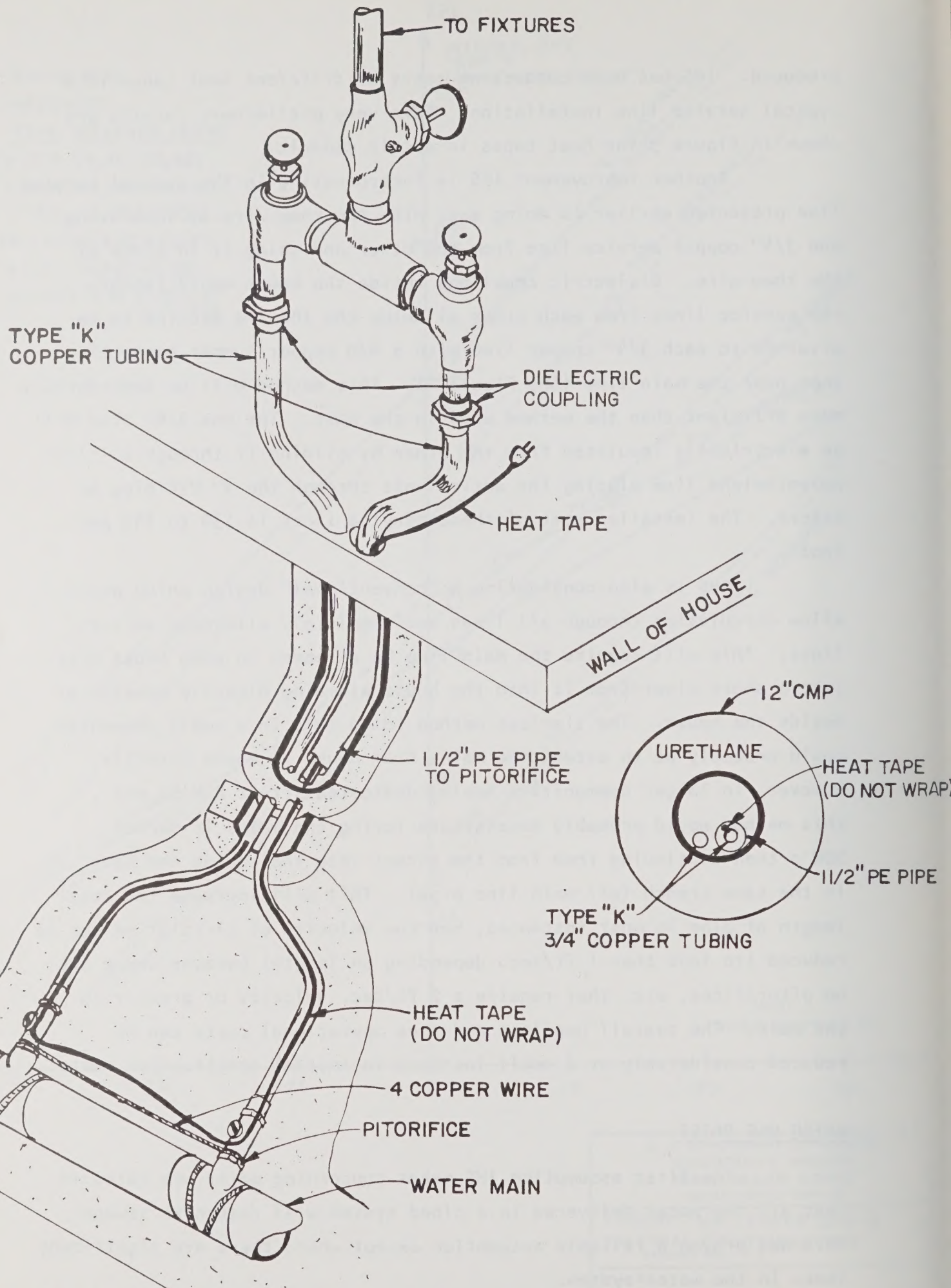


FIGURE 4. INDIAN HEALTH SERVICE IMPROVED SERVICE LINE DETAIL

Use rates can vary considerably within a given community depending on the season of the year. In most small systems, individual water meters are not economical and the home owner pays for his water on a lump sum basis independent of the amount used. With the typical winter problems of service line freeze-ups, he will leave his water running at night to reduce the possibility of having to pay to have his service line thawed. Typical water use rates are 70 gallons per capita per day in the summer and can vary from 80 to 200 gallons per capita per day in the winter. The city of Ketchikan in S.E. Alaska (not a permafrost area), for instance, experiences winter use rates of over 300 gallons per capita per day.

Water use rates such as these can cause real design problems, especially with respect to water supply and heating facilities and sewage treatment plants.

SUMMARY

In order to improve the health of the people in rural Alaska through environmental improvements, the IHS is trying to reduce the operation and maintenance costs as low as possible and still provide facilities that will accomplish the objective. This is being made more difficult with the passing of more restrictive laws that are not adequately funded to meet their obligations. It's meetings such as this that hopefully will bring out new ideas as to how these common problems can be solved more simply and economically.

PREPARATION OF AN OPERATIONS AND MAINTENANCE MANUAL

by

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When one becomes familiar with operating problems in isolated settlements of the Northwest Territories of Canada, it soon become apparent that some of the problems can be traced to operators and the limited information which they have available about the systems for which they are responsible.

While agreeing that the design engineer should not be directly concerned about the skill of the owner's operators, there does appear to be an obligation to recognize special conditions of extreme isolation and limited available expertise which may seriously affect the satisfactory performance of an otherwise good installation. Northern utilities require a more complete set of operating instructions, a clearer presentation of how systems were intended to function under various conditions and a more detailed listing of technical data, than their southern counterparts.

A "Specification for O & M Manuals" was developed by the Department of Public Works for application to installations in the permanent settlements of the Northwest Territories. This manual is a standard publication. It is not restricted to utilities, and applies also to mechanical and electrical systems in buildings. This paper is intended as an explanation of the requirements laid down in that specification.

Twenty years ago, the northerner required no manual to dip water from an ice-hole or to dispose of that plastic wonder known as the "Honey Bag". But a generation which started life as nomadic hunters are now involved with plumbing, flush toilets, electricity, central heating, electronic controls and similar equipment.

The fact is that much of the technology developed in the south during a century has swarmed north in little over a decade. This was dumped in the lap of the northern operator, who has tried to absorb

it and shown a remarkable ability in doing so. He has proven that he can perform well under pressure and it is not surprising if he sometimes fails to understand all the significant details in a system. After a system has operated for a few years and survived several emergencies, it may only remotely resemble the original. Such situations are not unusual and are indications that the designer failed to provide an adequate O & M Manual.

For those not familiar with the north, permit me to suggest a few reasons why an O & M Manual needs to be more complete for northern use.

1. Settlements are small and isolated, transportation is mainly by air, weather conditions can interfere with travel and communications.
2. The technical personnel are limited in numbers and experience, and have no one to turn to for immediate assistance except the manual.
3. Prints and specifications are seldom available longer than two or three years after construction and by that time, are of questionable accuracy due to the many modifications usually found necessary.
4. The cost of transportation limits the availability of servicemen from the south.
5. It is difficult to find skilled southern tradesmen who are both willing and capable of living in the north. It is equally difficult to find northern residents willing and able to be trained.
6. Staff turnover is high. The value of instructions often given to the operator on turning over a new installation, is limited to what he can remember and disappears when the operator leaves.
7. It is not practical to carry bulky information on small aircraft. Consequently, the information on the site in the manual, while primarily aimed at the operator, must also

provide basic information required by visiting Supervisors, Technicians and Engineers.

8. Finally, a high level of performance is expected from an operator and this can only be obtained if we provide the reference data required to perform at that level.

THE GENERAL FROM OF PRESENTATION SPECIFIED FOR MANUALS

1. Four copies are required. One is kept on the site for the operator; one is held by the Supervisor; one by the Regional Engineer; and, the master copy is held by the Head Office.
2. Hard covers are needed for protection of 20 years or more and must have permanent identification on the edge.
3. Changes seem to be always taking place. Loose leaf binders are needed to permit amendments for up-dating and must be a standard type.
4. Indexing must permit rapid entry.
5. A standard arrangement of chapters is needed. This is not apparent when considering a single system, but supervisors and engineers, with perhaps 50 manuals on hand, find a large time saving when information is arranged under the same chapter headings in each manual. This also reduces the cost of preparing, checking and maintaining manuals. This is a firm requirement which is often misunderstood by consultants when deeply involved with only one system.

THE STANDARD ARRANGEMENT REQUIRED

The manual is required to be prepared in eleven chapters, as follows:

Chapter 1 - Introduction

1. When the system is being installed, all details are known by all involved. We have difficulty convincing consultants

that in five years it may be difficult to determine the phase, year, system or in rare cases, the settlement to which a manual refers unless it is clearly identified.

2. No system is static. The user must be able to quickly determine if the manual includes the latest changes, and a standard first page should provide for this. The second page should list the consultant's, contractor's and owner's staff who were involved with original construction. There is often need to refer to these sources for information in later years.

Chapter 2 - Index

1. The intent is to provide rapid entry into the manual for specific information, which is the reason for the detailed break down of each chapter.
2. Since the manual cannot include all the information, it should include an index of all supporting documents.

Chapter 3 - Design Data

3.1 Background data are requested for future use. These data are often lost as staff changes and memories fade. Previous errors can repeat themselves, or the reason for some features of the design can be lost. If this happens, these features are unlikely to get much attention from anyone.

3.2 Design data

1. This information is essentially a listing of the final figures on which the design was based. It is not intended to include the details of how the figures were determined unless the information is essential. For instance, capacity in terms of population served would only be useful if the g.p.c.d. on which the design was based was also given.
2. When failures occur, these data can indicate the changes needed to avoid repeating the problem.
3. Bulk supplies go to settlements by sea-lift once per year. Estimates of energy consumption are needed to assure that

adequate fuel and electrical power is provided. These also guide the operator to areas which are not operating efficiently.

3.3 Built-in Allowance

If installations include equipment which is provided for emergency use, or future expansion, this must be clearly stated. You can't expect the operator to decide if an electric heat tape is provided to thaw a frozen line or to continually heat it. There is a human factor here. The operators, if in doubt, tend to turn everything on rather than risk a freeze-up. This can play havoc with electrical bills.

3.4 Accepted Risks

Can we economically provide for every possibility? I would say "Certainly Not". Having recognized this, it is damned unfair to mislead an isolated operator into a false sense of security. The designer's interest and reputation are both well served when he clearly states the conditions which the system cannot handle. I can recall at least two occasions when failure to provide this information resulted in damage to the system.

Chapter 4 - Schematics and Functional Data

Chapters 4, 5, and 6 are the most important in the manual.

Information on every component is required for three different purposes:

1. Data essential to understand the function of the component when related to the system as a whole.
2. Details of the make, model, size, etc., of each components with all details essential for ordering a spare part or replacement.
3. The method of operating and maintaining the component.

Manuals tend to concentrate on item #3, pay lip-service to #2 and ignore #1. Northern systems tend to be more complicated than similar southern ones due to the extra safeguards provided. When

emergencies arise, the operator needs a clear picture of the contribution each component makes to the operation. We tried combining the function and the model details in the same table. This seemed to avoid unnecessary repetition, but it was found that the resulting mass of data confused the operators. For this reason, the standard arrangement called for them to be clearly separated.

Chapter 4 consists essentially of a table giving the number, name, location and function of each component with a schematic flow diagram, in fold-out form, for easy cross reference, with each component identified on the flow diagram with the same number as used in the table for that component.

Some have questioned the need for the location column. We have found that new operators have difficulty tracking down some components, particularly when they are out of sight in utilidors or wells, or behind walls.

We have difficulty convincing consultants that drawings must be reduced to 11" x 17" for inserting in the manual. The large drawing is too bulky, its weight tears it loose and it gets lost; if put in folders, it soon falls out, folding and unfolding soon tears it, and it is very unwieldy to refer to in cramped areas. We consider the 11" x 17" to be the largest drawing which can conveniently go into a manual. It is readable, and can be left folded out during field use without inconvenience.

Chapter 5 - Component Details

1. The companion chapter to chapter 4, consists of a table listing the same components in the same order, followed by 11" x 17" reduced size prints of as-built construction drawings, with all components numbered to match the flow diagram.
2. The prime purpose here is to provide the information required for ordering of parts or replacements.
3. A secondary purpose is to provide the information needed to return the components to their original locations if they get shifted around during emergencies. When faced

with a critical situation, an isolated operator often robs motors, pumps valves etc., from secondary systems in order to keep the most critical systems operating. When replacements finally arrive, it is not easy to sort out the mess and get everything back to its proper location. The information in this table can be very helpful.

Chapter 6 - Operating Procedures

1. Primarily for use by the operator or supervisor.
2. This is best set up as a table or in step form. Avoid wordy descriptions. To many operators English is only a secondary language.
3. Essentially this is the written record of the verbal instructions given on take over to the owners operator.
4. The scope of instructions needs to be adjusted to conditions in the settlement. Minimum content is adequate for large communities and maximum content is essential for small isolated ones.
5. The new operator will rely heavily on this chapter until he becomes familiar with the system. But emergency instructions should be very clearly laid out, because they don't occur often enough to become familiar to the operator.
6. It is not intended to include details of the standard operations which the operator should know for any system. These should be listed in brief form, at their proper place, for reference only. Provide in detail all information which is peculiar to this system. Of particular importance is the correct sequence for bringing components on line and the precise meaning of coloured indicator lights and warning alarms.

Chapter 7 - Lubrication and Maintenance Schedules

1. Lubrication should be condensed into table form for these reasons:

- (a) It helps in preparing annual re-supply orders.
 - (b) It tells the operator where special lubricants are required and prevents him drifting into using one oil and one grease for everything.
 - (c) It provides a master from which copies can be printed. These can be discarded when they gather too many greasy smears. This avoids mixing the grease and the manual, which certainly needs to be avoided.
2. We now find that the consultant does not usually have the expertise required to prepare this chapter. If they index it, and provide the tabbed divider with information about any special alloys or treatment which may not be readily identified, then the maintenance engineers will prepare the remainder.

Chapter 8 - O & M Records

This chapter will also be filled in by D.P.W. staff.

Frequently, operating logs, annual inspections, break down cause and frequency, and similar records are kept and filed separately. This chapter is intended to contain a sample page from each, to advise the operator what records to keep and the potential user, what type of information can be obtained and where it is filed.

Chapter 9 - Testing and Certification Data

- 1. This provides information on what equipment requires a boiler inspection, fire inspection or safety inspection and records these, as carried out throughout the life of the system, including any adjustments or changes required.
- 2. Final balance reports assist in returning a system to normal operation after any emergency improvisation has taken place.

Chapter 10 - Manufacturers' Brochures and Data

Sometimes this section is the only part of the manual which has been provided. This is totally inadequate.

1. Because this is a bulky section and is located at the back of the manual, it was found convenient to provide the detailed index at the beginning of the chapter instead of in the index at the front of the manual.
2. The need for an operating and maintenance brochure instead of a sales brochure is very important. When you have the equipment, you aren't interested in how wonderful it is supposed to be, but rather "how to keep the damned thing running".
3. Where a brochure lists several sizes or models, it is essential to clearly mark the specific one provided. Operators have waited months for a replacement part only to find that they ordered the wrong one. We prefer a red marking in order to attract the operators attention.
4. It is very useful to identify the component with the same key number used on the tables and diagrams of Chapters 4 and 5. This becomes absolutely essential when several similar components are all in the same brochure. The difference is usually very small and may not be fully understood by the operator.
5. The inclusion of shop drawings is essential for nonstandard items. These need to be reviewed and marked to reflect the actual item provided and any alternates or choices listed on standard shop drawings but not always provided.

Chapter 11 - Appendix

1. Probably the main items here are progress photographs. A record of every buried valve, branch connection, underwater installation and similar details which are impossible to obtain easily in the future, when repair or replacement is needed, is essential. We find few manuals are provided

with photographs, although we suspect that the photographs exist somewhere.

2. Other general progress photographs are of great value. They sometimes provide information never recorded or considered of any value at the time of construction. A single photograph can reveal more than several pages of descriptions. They are very useful for recording full layout/labels/and readings/ of control panels; interiors of utilidors, equipment layout in crawl spaces, and details of covered heat tapes.
3. Since a standard format was specified, this chapter provides the flexibility for including various information which is essential, but not specified in the standard layout for the manual.

CONCLUSION

For any installation of utilities in the arctic there are three factors which play a large part in producing a continuously satisfactory operation:

1. the design;
2. the quality of construction; and
3. the quality of the O & M manual.

The design presents problems, particularly when the cost of operating and maintaining has not been fully considered.

The construction quality can be influenced by isolation and climate. It is often a lower standard than was expected by the designer.

The problems from both these are dumped on the operator and, after five years, the reputation of both the designer and the contractor may depend on how carefully they prepared the O & M manual. It may well be that the O & M manual is of equal importance with design and construction, if systems are to be kept operating properly under arctic conditions.

A REVIEW OF SELF-CONTAINED TOILET SYSTEMS
WITH EMPHASIS ON RECENT DEVELOPMENTS

by

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INTRODUCTION

The issues of safe water supply and sanitary human waste disposal have been a major concern of northern public health officials for many years. The incidence of communicable diseases in northern communities is generally as high or higher than anywhere else in North America. While the reasons for such a high communicable disease incidence are complex, most authorities cite the primitive methods of handling and disposing of human waste as a major causative factor.

The objective of this paper is to review self-contained toilet systems in light of the criteria which must be met for northern application. While some of these systems may be considered interim measures, pending the adoption of sewer and water systems, others may provide a viable long term method of handling human waste.

BACKGROUND

Sanitation in northern communities is complicated by the difficulties of providing conventional sewer and water systems in areas where permafrost, bedrock, cold weather, low or non-existent economic base in the community, population size and physical layout of the community, etc., make it economically and technically difficult to provide such services.

As a consequence, nearly all northern communities rely to some extent on service vehicles to supply water and remove human waste from homes and other buildings. Although flush toilets of one type or another connected to sewage holding tanks are becoming more prevalent, the majority of unsewered homes in the north rely on bucket toilets with plastic "honey bags" to receive and dispose of human waste. While

"honey bags" are more aesthetically acceptable than outdoor privies, and are more sanitary than non-disposable, unlined pails, they still constitute a major sanitation and health problem in the communities. Heinke (1974), writing on concentrated waste disposal, noted that:

"The elimination of the use of "honey bags" would be a very important improvement in the living conditions of northern communities by contributing to a reduction in waste borne diseases."

Hanks (1967), in summarizing the results of a literature search on the relationship of solid wastes (including human waste) and disease noted:

"The communicable diseases most incriminated are those whose agents are found in fecal wastes - particularly human fecal wastes. Where these wastes are not disposed of in a sanitary manner, the morbidity and mortality rates from fecal-borne diseases in the population are high. Despite the fact that other factors are known to contribute to reduction of these rates, the inescapable conclusion is that the continued presence in the environment of the wastes themselves is the basic causative factor. Therefore, transmission - whether by direct contact, vector transfer, or indirect contact - is due to environmental contamination by these wastes."

Heinke (1973), in an earlier report on solid waste disposal in communities of the Northwest Territories, detailed the sanitation problems that occurred during the collection and disposal of "honey bags." In all communities surveyed, breakage and scattering of honey bag contents during pick-up and disposal was a relatively common occurrence. In those communities with a regular pick-up schedule from inside the houses, there was a small incidence of breakage. Where bags placed outside the homes before pick-up, breakage of bags by children, birds or dogs, was a common occurrence. Ripping of bags during collection was also a problem, as the unprotected bags froze to the refuse container or the ground, and came apart when lifted by the collection crew. In all communities there was some spillage of bag contents contaminating the ground and thereby creating a potential health hazard.

The ultimate disposal of "honey bag" contents also presents problems for most northern communities. Those lacking sewer facilities normally dump the bags at the local refuse sites, or in a sludge pit or lagoon. Unless these sites are chosen with care, contamination of the environment and even the local drinking water supply can occur. The dumping of untreated wastes in a climate where biological breakdown is extremely slow, ensures the survival of pathogens for a long period of time. Since in most cases, it is impossible to close off the dump sites from wild animals, dogs, birds and other disease carrying vectors, the possibility that pathogens will be returned to the community is high whenever untreated human waste is discarded in this manner.

While the installation of conventional sewer and water systems to replace trucked services, including the "honey bag", would seem to be a desirable goal, in many communities such systems are not practical in the present or readily foreseeable future. Even where sewers could be installed without a prohibitive cost, the availability of a plentiful water supply is often a limiting factor. Under these conditions, the conventional flush toilet is not a viable method of handling human waste. Grainge and Slupsky (1973), listed and evaluated a number of alternatives to the conventional toilet for use in arctic work camps and northern communities. Their evaluation included the following units:

Portable Units

1. Bucket Toilet
2. Portable Chemical Toilet
3. Portable Minimum-Flush-Water Toilet

Fixed Units

1. Septic Toilet
2. Chemical Toilet
3. Minimum-Flush-Water Toilet
4. Vacuum Toilet
5. Chemical Toilet with submersible splash pan
6. Recirculating-Chemical Toilet
7. Incinerating Toilet
8. Continuous Aeration, Closed-Cycle Toilet

While each of these units offer advantages over the conventional toilet system in situations where sewer systems are lacking and water supplies are limited, all suffer some disadvantages, failing either in aesthetics, capital and operational cost, operational problems or sanitary aspects. Alter (1973), writing in the Northern Engineer noted that:

"If wastes may be kept concentrated and confined at the point of origin until they can be rendered non-objectionable, it is simple to control them."

Alter presented the characteristics of a commode suitable for use in polar regions, as shown in Table 1.

Alter's objectives for the "Polar Palace" suggest that the ideal toilet for northern application must be compatible with the efficient use of water, energy and other resources as well as being economical to purchase and to operate. These objectives seem to effectively rule out the use of the standard flush toilet and the centralized sewage collection system for most northern communities. The ideal toilet system for northern application would be one which uses little or no water, or one in which the flushing fluid, if used, is renovated and recirculated. The ideal toilet system would also isolate the waste from the home environment and treat the waste in the receiving container so that disposal could easily be made without endangering the environment or health of the community.

While the idea of adopting a non-flush toilet as more than an interim measure may be difficult for some people to accept, a number of authors (Love, 1975; Lindstrom, 1973; Rybczynski *et al*, 1973) suggest that the use of water to transport human waste should be carefully reconsidered. The dispersion of human waste in the water used as a carriage medium, only increases the difficulty of later separating the waste and effectively rendering it environmentally and sanitarly harmless. While there is no question that the use of water to transport wastes in central sewer collection systems has brought great sanitary benefits to the urban environment, the use of these same systems, coupled with our failure to provide adequate treatment has caused major pollution problems in the lakes, rivers, and streams of the

TABLE 1. CHARACTERISTICS OF A COMMODE SUITABLE FOR USE IN POLAR REGIONS

<u>Objective to be achieved</u>	<u>Desirable Characteristics</u>
1. Serve as an effective barrier against disease transmission.	Compatibility with mission Performance life of facility population served
2. Be aesthetically acceptable.	Ready procurement Easily shipped
3. Not degrade the quality of the natural environment.	Easily installed Handles all normal wastes
4. Provide the maximum of comfort and safety necessary in man's adjustment to cold region living.	Protection of health and safety Effective barrier to disease spread Wastes inaccessible to vermin Free from fire or safety hazard
5. Be capable of relatively dependable "fail safe" function at all times.	Aesthetic features No odors
6. Be compatible with the pattern and sequence of community development.	Acceptable appearance Comfortable to use
7. Be economically feasible.	Operating characteristics Simple to operate
8. Be simple to build and operate.	Suitable for repeated use Easily maintained
9. Be compatible with efficient use of energy, water and other resources.	Easily cleaned Few repair or replacement parts
	Economy Conserves water Conserves manpower Uses minimum power

From Alter (1973)

industrialized world. In light of advances made in the technology of dry toilet systems, the insistence on continued use of the standard flush toilet and the conventional sewer system should be carefully reconsidered.

CATEGORIZING TOILET SYSTEMS

This presentation is designed to examine a number of types

of self-contained toilet systems to determine how they measure up to the objectives required for application to the north. The systems have been divided into four categories as follows:

1. Dry Storage and Removal Systems;
2. Liquid Borne Storage and Removal Systems;
3. Liquid Borne Treatment Systems; and
4. Dry Treatment Systems.

A discussion of each category is given in the main body of this paper, while reference to specific configurations is given in the Appendix. It should be noted that some equipment may fit into more than one category depending on the way it is set up in a complete system. For example, the vacuum toilet may be used in a liquid borne storage system or a liquid borne treatment system depending on whether it is coupled to a holding tank or some type of treatment or incineration system. While descriptions of many systems are presented in the Appendix, all possible configurations have not been covered.

"Dry" Storage and Removal

The term dry storage and removal is used to categorize all types of toilet systems which act as storage receptacles and which do not use liquid as a transport medium. The chamber pot, toilet pail, bucket toilet, honey bag, freezing toilet and packaging toilet all fall into this category. The dry toilet is basically a receptacle which receives the waste and holds it until removal by some manual method at a later date. Most dry storage toilet systems are unsanitary, aesthetically offensive but relatively inexpensive to purchase and operate. For this reason they are still the most common method of handling human waste in smaller northern communities. Two new methods (freezing and packaging) which upgrade the aesthetics and sanitation of the dry storage systems will be elaborated on later in the paper.

Liquid Borne Storage and Removal

Toilet systems which use water or some other liquid medium to convey the waste to the storage container and/or to the collection

vehicle fall into this category.

Pump out tanks or holding tanks, chemical toilets, vacuum toilets, non-aqueous flushing systems are the type of systems included in this group. These systems use liquid as the conveying medium and allow the waste to be pumped to and from the collecting vehicle rather than requiring manual handling of the waste.

These systems are, in general, more sanitary than dry systems since in most cases they isolate the waste from the home environment by conveying it immediately to a closed holding tank. The ability to mechanically remove the waste from the holding tank to the collection vehicle via pumps and hoses, reduces the risk of accidental spillage and contamination of the soil in the vicinity of the home.

While these systems have decided advantages over the honey bag system, their universal adoption for northern communities has been somewhat restricted by a moderate capital cost, a high operating cost, and the requirements of a generous water supply to act as the conveying medium.

Liquid Borne Treatment System

Liquid borne treatment systems are the most common method of handling human waste in temperate regions of North America when conventional sewer systems are not available. The most common liquid borne treatment system, the septic tank and tile field is only usable in limited areas of the north where permafrost is not present.

Other systems in this category include various biological units and in larger configuration, physical-chemical treatment units. Since disposal of effluent is a major problem in northern areas, most liquid borne treatment systems are not practical unless they are designed to recycle the liquid used to convey the waste. Although such systems have been developed and are, in general, sanitary, the use of recycled liquid is often aesthetically objectional unless the treatment process is exceptionally good.

Liquid borne treatment systems are expensive to purchase, complicated to operate, and have space requirements which make them unsuitable for use in most existing homes. In most cases, a liquid

borne storage and removal system is at present a more desirable arrangement for most northern communities.

"Dry" Treatment Systems

Dry treatment refers to systems which receive the wastes without using liquid as a transport medium and which provide treatment in the receiving container. Three types of devices fall into the category of dry treatment:

- a. incineration which uses auxiliary energy to dry and incinerate the waste;
- b. anaerobic digestion which partially treats the waste with the evolution of noxious odors; and
- c. composting which uses aerobic decomposition to turn the waste into an environmentally acceptable soil like product.

Incineration toilets have been used in isolated instances in the north where economic considerations are outweighed by special requirements to maintain sanitary conditions. In general, incineration has excessive energy requirements and is, therefore, unsuitable for most northern situations since energy in any form is expensive.

Anaerobic digestion such as is found in the large vault toilet has been used but is aesthetically and sanitarily unacceptable because of the inability to close off the receptacle from the home environment. The production of foul odours and the problems with flies and other disease carrying vectors as well as the incomplete treatment afforded the waste, makes the vault type toilet even less desirable than the honey bag system.

The composting toilet, while overcoming many of these problems, has deficiencies which will be discussed later in the paper.

NEW TECHNIQUES IN DRY STORAGE

Two recent innovations in dry storage technology have the potential for upgrading the sanitary conditions and aesthetic acceptability of dry toilet storage systems. Both have been developed in the Scandinavian countries which have many elements in common with

the North American arctic.

The freezing toilet (illustrated in Figure 1) uses cold to preserve the waste and prevent biological breakdown with its accompanying odors. The basic configuration is to place a toilet seat over a small insulated freezing compartment, cooled by an electrically operated compressor. The waste is received in a large water proof paper bag. Once the waste is deposited, it is quickly frozen, preventing the decomposition from taking place and making it unattractive to flies and other insects. The toilet seat is warmed by heated air from the compressor coils, thereby protecting the user from suffering discomfort from the cold.

After the bag capacity has been reached, it is manually removed and replaced with a new bag. The problems of bag breakage common to the "honey bag" system are non-existent, as long as the bag is handled in the frozen state.

The freezing toilet is a relatively small change in concept from the standard bag toilet but by affecting the aesthetics and sanitation may have a major contribution to make in northern human waste disposal. It is moderately expensive in capital and operating cost. Models should be available on the North American market in the near future at less than \$500 each. The compressor, which runs

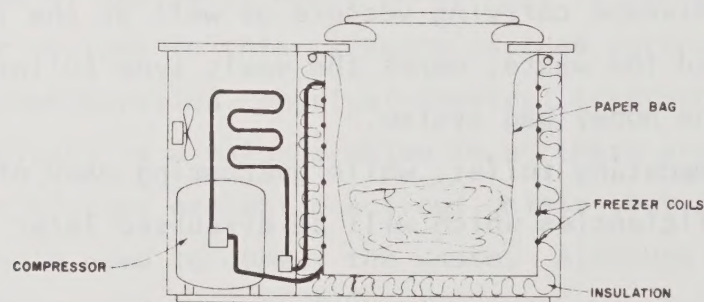


FIGURE 1. FREEZING TOILET

intermittently, only requires a current draw slightly over 100 watts. The energy cost, even at northern electric rates, should be low. Other costs include the cost of bag collection, and disposal, and the purchase of the large waterproof paper bags.

The packaging toilet (illustrated in Figure 2) also attempts to improve the sanitary and aesthetic qualities of the bucket toilet. Waste is received in a plastic tube which is heat sealed after each use to form a series of "sausages". By sealing each segment of waste received, the waste is immediately isolated from the home environment, preventing odors and the spread of pathogens by flies or other vectors. Unlike the freezing toilet, however, decomposition of the waste continues, making regular collection of the waste an important step in maintaining sanitary conditions. The isolation of the waste into small packages should help to control the amount of breakage during the collection procedure.

Capital cost of the packaging toilet is considerably higher than for a standard bucket toilet. However, its improvement in sanitary and aesthetic qualities may make it worthwhile to consider for adoption in northern communities. Its physical configuration, however, is such that mounting of the unit with the collection bag beneath the floor may be difficult in many northern homes. The additional packaging material may also cause problems if the waste is ultimately disposed of in some sort of treatment system.

Both the packaging and freezing toilets are systems that should be considered as replacements for the honey bags in northern communities. Although they are obviously not the final answer to human waste disposal, they have the potential to upgrade the present "honey bag" systems and contribute to better sanitation in northern communities.

NEW DEVELOPMENTS IN DRY TREATMENT

The use of composting toilets to manage human waste within the home environment is a relatively new concept in the technology of waste disposal in North America. Although the use of composting as a method for handling human waste has been growing for several years in the Scandinavian countries, North American technology has concentrated

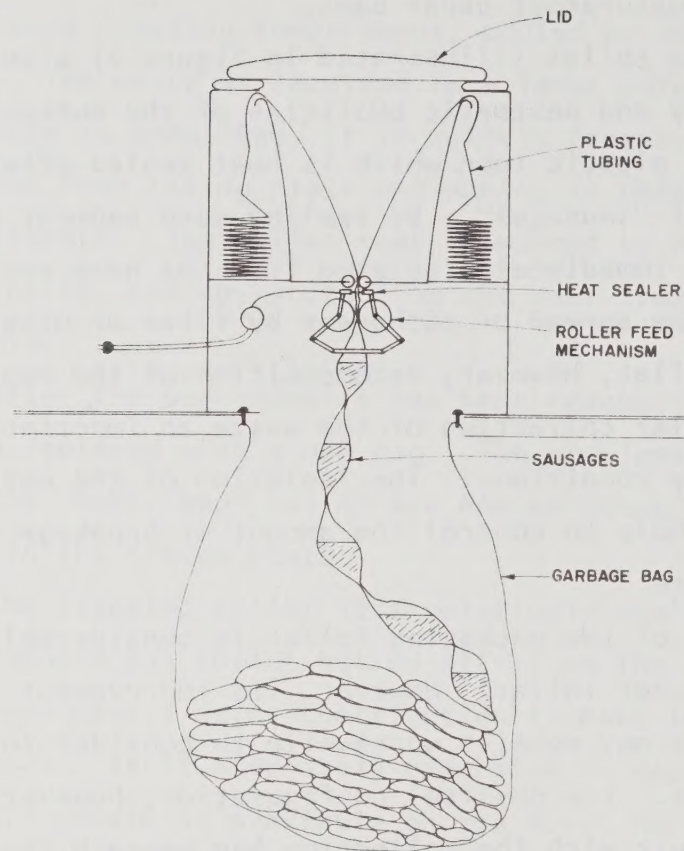


FIGURE 2. PACKAGING TOILET

on using water carriage to remove waste from the home environment. The idea of the composting toilet was conceived by Carl Lindstrom in Sweden in the 1930's. Almost all subsequent development has taken place in the Scandanavian countries where as many as 50 models have been marketed to serve the needs of the cottager and isolated home.

This section will examine the principles of composting and the various types of composting toilets available to evaluate their usefulness in northern communities.

Composting is a process of microbial breakdown of organic material taking place in the solid phase. It differs from fermentation or digestion which are liquid phase processes, in that pores or passages in the material allow the movement of gases and air into and out of the

material. Composting can proceed anaerobically, aerobically or in some combination of the two processes. In general, anaerobic composting proceeds slowly with the evolution of small amounts of heat and with the production of end products such as methane, hydrogen sulphide and other odoriferous compounds. Aerobic composting in general proceeds at a faster rate, releases more heat of reaction and does not produce foul odors. The breakdown of organics is much more complete than in the anaerobic process with the main end products of breakdown being carbon dioxide and water.

Composting has been used since farming began to decompose waste agricultural organics into soil fertilizers and conditioners. The earliest composting practices which are still used throughout the world today, involve the simple piling of organic material in a large heap or pit and leaving it for a year or more until the material decomposes. The garden compost pile and the barnyard manure pile are examples of this slow, primarily anaerobic composting process. Modern high rate composting is generally aerobic and is carried out by thermophilic aerobic organisms under ideal conditions. In high rate composting, an attempt is made to maintain temperatures in the thermophilic range of 45° - 65°C ; the compost has access to oxygen; moisture content is maintained in the 50 to 60% range; pH is slightly above 7; particle size is small and the carbon-nitrogen ratio is approximately 25:1. Under these ideal conditions, production of a stabilized humus may take place in less than one week. Modern high rate composting techniques are generally designed to create an ideal environment for the micro-organisms to carry out the decomposition process. Modern composting plants stabilize a wide variety of materials, including municipal refuse, animal husbandry wastes, domestic sewage sludge, fruit and vegetable processing wastes and meat packing wastes.

Composting of human waste to kill pathogens and to provide a safe sanitary method of disposal has been used since ancient times. The conventional pit privy, which has been around throughout the evolution of civilized mankind, acts in most cases as a low rate anaerobic composter. In the pit, excess moisture is drained off into the surrounding soil, while the remaining solids undergo a slow

anaerobic decomposition. One of the first attempts to improve the composting process in the treatment of human waste was developed in India in early 1920's (University of California, 1953). The process takes place in shallow pits or in piles on the open ground. Alternate layers of putrescible materials such as human waste, garbage, manure, etc. are interlayed with layers of relatively stable organic material such as leaves and straw. The mass is turned two or three times during its six-month to one-year composting period. The process is a forerunner to modern windrow composting techniques. The heat developed in the piles, effectively neutralizes pathogens in the human waste, rendering the compost suitable for use as soil conditioner and fertilizer.

Composting Toilets

The development of aerobic composting toilets for handling human waste inside a house or other structure is a relatively new idea, although Flood (1926) describes one of several types of toilet vaults used in the early 1900's, which appears to have operated as a composting toilet. The toilet vault produced a product which after drying during the summer vacation period, was able to be burned, leaving an inorganic ash as a residue. The toilet vault operated by drawing air from the school interior through the basement receiving vault and exhausting it by way of a natural draft chimney to the atmosphere. Even with a school population of several hundred children, a visitor to the school commented on the efficient operation of the unit, which produced no odors. The principal of operation would seem to be similar to modern composting toilets in that excess moisture was evaporated and the remaining solid waste decomposed in an environment kept aerobic by the large volume of air drawn through the toilet vault.

The conscious development of composting toilets for use in individual buildings and homes began in Sweden over thirty years ago. Units based on these early designs utilize a large container located in the basement of the building to receive solid wastes from the toilet and kitchen (Lindstrom, 1973). (See Figure 3.) Two chutes accept the waste which falls onto an inclined slope, covered with peat moss and soil. The container is vented through the roof of the building.

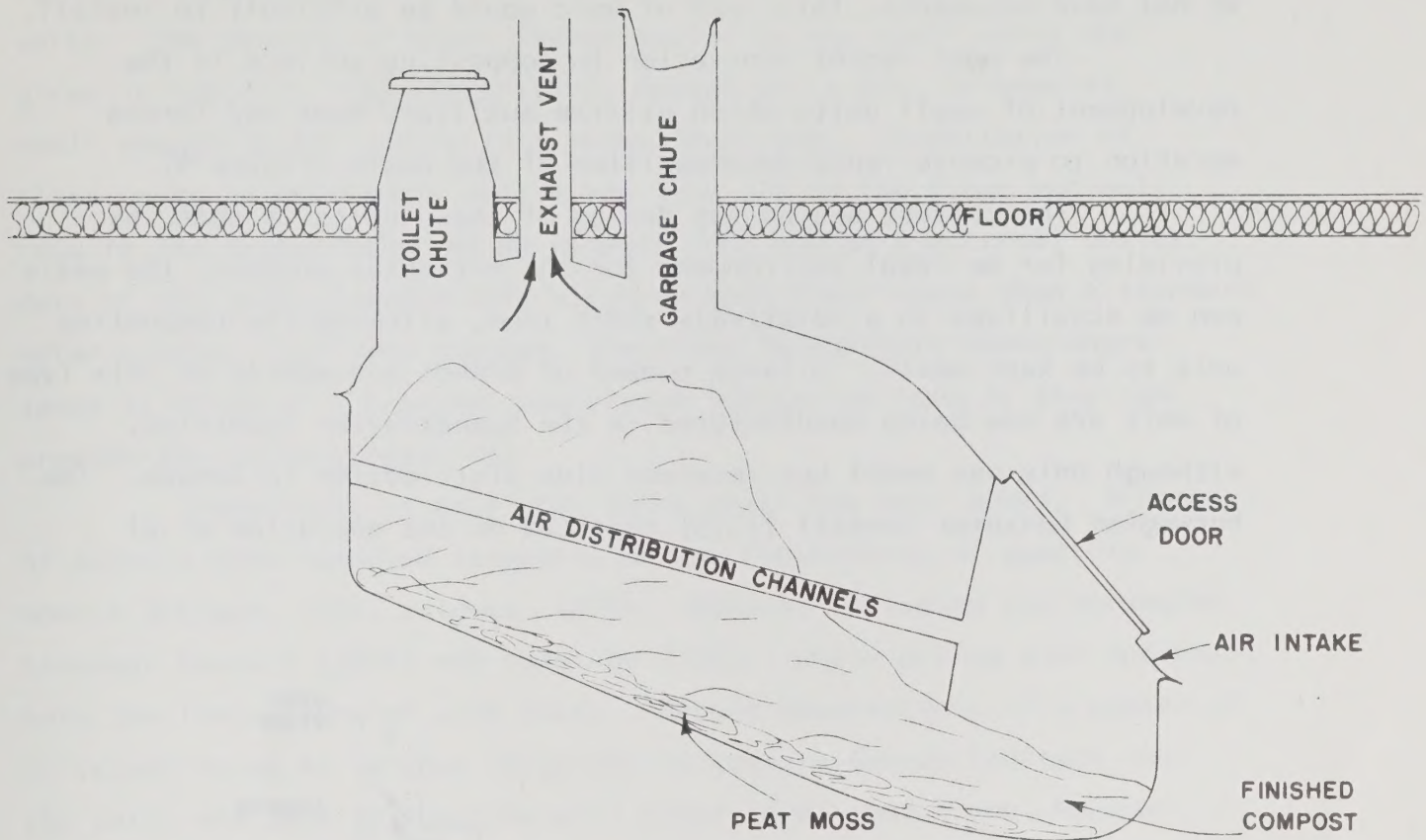


FIGURE 3. INCLINED SLOPE COMPOSTING SYSTEM

Natural convection draws air through and over the compost heap, keeping it aerobic and evaporating excess moisture. As the organic material decomposes, it slides down the inclined slope to the storage chamber where it remains until manually removed. Because of the large size of the storage chamber, and the length of time the mass undergoes decomposition, removals from the unit are only required once every two or three years, even when the unit is in constant use. The large size of the container and volume of material retained, allow this type of unit to function under wide loading fluctuations. The major drawback is the size of the composting container, which prevents installation in homes already constructed and presents difficulties in those which lack a basement. Since most homes in permafrost areas

do not have basements, this type of unit would be difficult to install.

The most recent innovation in composting toilets is the development of small units which utilize auxiliary heat and forced aeration to promote rapid decomposition of the waste (Figure 4).

The concept behind the design of these units is that, by providing for an ideal environment for the microbial process, the waste can be stabilized in a relatively short time, allowing the composting unit to be kept small. A large number of brands and models of this type of unit are now being manufactured in the Scandanavian countries, although only one model has received wide distribution in Canada. The Norwegian Consumer Council (1975) reported on the operation of 21

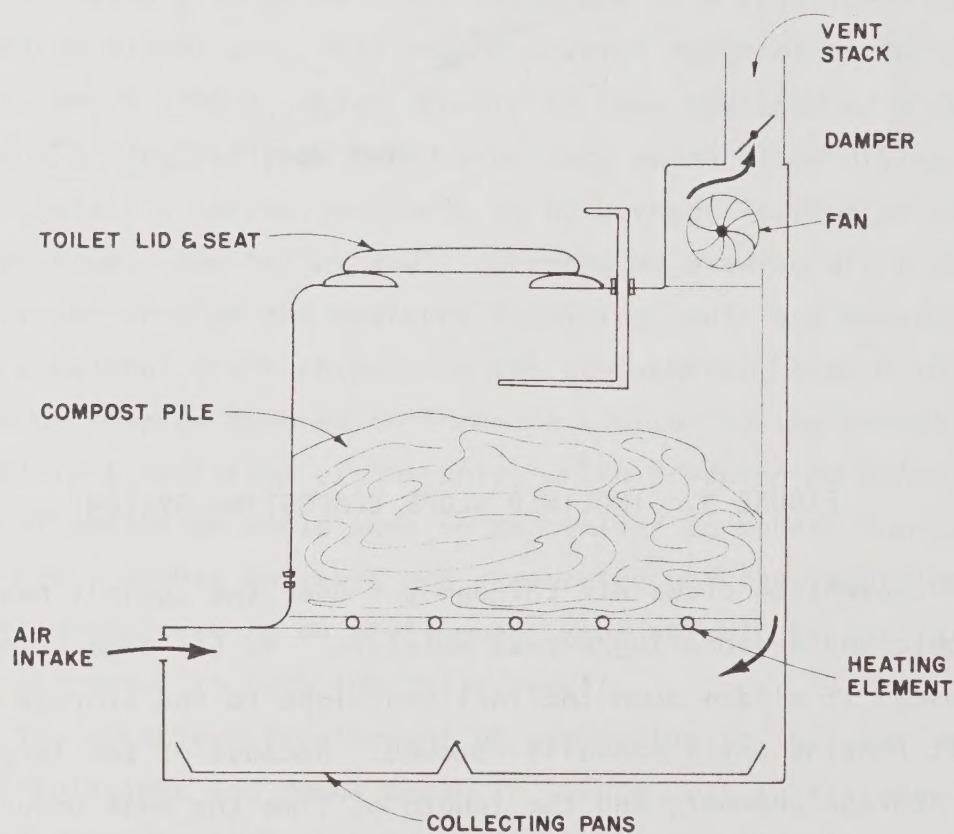


FIGURE 4. SMALL ELECTRICAL HEATED COMPOST TOILET

types of composting units, including eight small electrically heated units. The results of their investigation on the small units are given in Table 2. The electrically heated units are, in general, small enough to fit easily in a normal bathroom. Installation of these units is relatively easy since they sit on the floor and only require the installation of an exhaust vent and an electrical outlet. Most of the units require only slightly more floor space than a standard water closet. For size reasons, their use in northern homes where space is often at a premium, would seem logical as long as they can provide the service required.

Experience to date with these units has been mixed. A number of authors have reported favorably on the functioning of specific models (Eklund, 1974; Valdmaa, 1974). Others, including the Norwegian Consumer Council (1975) and McKernan (1975), while giving some approval, note the limitations of such units. Recent observations of a number of units monitored at various locations in western Canada indicate that the units are able to function well under ideal conditions, however, because of the small capacity of the composting container, they are easily upset by shock loading of organic and liquid wastes. Since the units rely on evaporation to remove moisture, excessive amounts of urine, such as might occur during a party at the home, can easily saturate the compost, preventing oxygen from penetrating into it and, thus, allowing it to become septic. Once anaerobic conditions are established, unpleasant odors are produced which will become objectionable unless the ventilation system works efficiently. Once a toilet has become septic, it takes considerable time to re-establish aerobic conditions. Excess humidity has also led to corrosion of electrical connections in some units causing failure of the fan and heating equipment. Units subject to underuse do not generally give problems as long as sufficient moisture is retained in the compost to keep the microbial populations viable. If the compost dries out, the microbial action slows or stops and the compost pile builds up rapidly.

Other problems to be expected in the units include uneven distribution of moisture in the humus which causes portions of the compost to dry out and cake. The caked material can become very hard,

TABLE 2. SMALL TOILETS WITH ELECTRIC HEATING ELEMENTS

1. Trade/Model Name	Bio-do	biolo ⁵	KPS Milj-klosett MK73	Mullbank	Mull-toa	Mull-toa Jumbo	Multex	Tropic
2. Approx. Price in Norway in Cdn. Dollars	\$544.00	\$553.00	\$461.00	\$341.00	\$544.00	\$655.00	\$425.00	\$425.00
3. Dimensions, cm	61X99X68	62X80X63	58X105X75	60X108X78	54X77X71	61X100X76	54X72X64	56X84X69
4. Air Fan	Yes	Yes	Heating Coil	Yes	Yes	Yes	Yes	Yes
5. Heating Element	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6. Rated power, Watts	250	50+ past. ⁶ plate 180	280	160	180	225	145	365
7. Vent pipe, diameter, mm	75	110	75	110	50	50	50	50
8. Velocity of air in vent pipe, m/sec.	1.5	2.5	1.0	2.0	4.5	3.5	4.0	3.0
9. Quantity of air from vent pipe, l/sec.	6.5	18.0	4.0	16.0	9.0	7.0	8.0	5.0
10. Capacity, number of persons	4	4	4	4	4	6	4	4
11. Capacity time, number of days	43	46	48	48	48	48	41	48
12. Total capacity, kg	220	232	260	260	260	370	212	260
13. Kitchen waste, kg	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
14. Reduction of weight in test period, %	72	85	75	83	91	85	80	82
15. Temperature in mass, °C	26	55	22	22	22	26	21	22
16. Intestinal bacteria, sanitation	Satisf.	V.Good	Good	V.Good	V.Good	Satisf.	V.Good	Good
17. Composting degree, visual analysis 2 months after last use	Good	Good	Good	Good	Good	Good	Good	Good
18. Instructions for use	Satisf.	Satisf.	Good	Good	Good	Good	Good	Good
19. Functioning, total evaluation based on actual load	Poor	Poor ⁷	Satisf.	Good	Satisf.	Good	Poor	Satisf.

5-Currently not sold in Norway. Norges Elektriske Materiellkontroll is testing the toilet.

6-The toilet has a heating element and an element for pasteurizing the ready compost.

7-Because of weak construction of the stirring mechanism.

8-This toilet is available in a propane-operated form as well.

Notes on some items in Table 2

Item 2.	<u>Price</u>	- The prices are approximate sales prices including value-added tax, given by manufacturers/importers in September, 1975.
Item 6.	<u>Consumption of power</u>	- The rated power is the reported maximal consumption of power for the toilets. As the heating element will not be continuously on, the average consumption is much lower.
Item 16.	<u>Intestinal Bacteria</u>	- Test results showed that sanitation of the mass was satisfactory in all toilets. The following evaluation scale was used: Very Good = less than 100 bacteria per gram. Good = 100 - 1,000 per gram. Satisfactory = 1,000 - 10,000 per gram. None of the toilets had bacterial counts exceeding 10,000.
Item 17.	<u>Composting degree</u>	- A visual evaluation was carried out two months after the last addition to the mass in the toilet, and the following evaluation scale was used: Good = soil-like odor, soil-like structure. Satisfactory = soil-like odor, but no soil-like structure. Poor = bad odor, porridge-like structure.
Item 18.	Instructions, and <u>Item 19.</u>	- Functioning, total evaluation - Evaluation scale as above: Good, Satisfactory, Poor.

Table translated from Norwegian Consumer Council Report #10 (1975).

making it extremely difficult to mix and aerate the compost pile. With these conditions, the microbial action ceases in the dry portions and the compost heap continues to build up instead of breaking down and falling through the screens into the humus collection pans.

The breakdown of sealing materials between the sections of the units is another serious problem. This allows odors to seep out into the room where the toilet is situated. Improper installation can also cause problems. If the vent pipe is not insulated in the attic and above the roof, condensation will occur returning the evaporated moisture to the unit causing it to become septic. Improper sealing of the exhaust vents will also allow odors to escape into the house.

The operation of a specific composting unit and the characteristics of the humus generated by it were studied by Valdmaa (1974). He found that the humus was quite mineralized, retaining on an average less than 50% organic material in the dried sample. The material also contained good quantities of trace elements and nutrients making it quite useful as a soil conditioner. Analysis of total coliform and fecal coliform bacteria showed that numbers of these organisms were greatly reduced from those typically found in human waste. Several of the units which Valdmaa sampled gave fecal coliform numbers of less than 10 per gm of dry sample. While these reductions are not unexpected, the significance of the numbers of coliform remaining viable need to be assessed so that a realistic recommendation on disposal of humus can be formulated.

Results of chemical analysis reported by Valdmaa on the humus compared with typical digested sludge and farmyard manure are summarized in Table 3.

Valdmaa also reported on the bacterial analysis of the humus in eight toilets. His results are given in Table 4.

The question of whether or not composting toilets provide a safe sanitary method of treating and disposing of human waste remains to be determined. Rodale (1971) suggests that, all things considered, the compost toilet may be a more sanitary method of handling human wastes than the conventional flush toilet. The flush toilet, although

TABLE 3. COMPARISON OF TOILET COMPOST, DIGESTED SLUDGE, AND FARMYARD MANURE

Constituent Analyzed			Mullbank Humus	Digested Sludge	Farmyard Manure
pH			6.9	6.9	8.5
Kjeldahl Nitrogen	in % of	dm	2.5	4.9	2.2
NH ₄ -N	"	"	0.9	1.0	0.3
NO ₃ -N	"	"	0.1	0.1	0.1
Tot.-N	"	"	2.6	5.0	2.3
Org.-N	"	"	1.6	3.9	1.9
Org. C	"	"	22.7	34.2	44.1
Org. matter	"	"	47.5	59.0	76.0
Phosphorous (P)	"	"	1.5	1.5	0.6
Potassium (K)	"	"	3.1	0.4	2.1
Calcium (Ca)	"	"	1.6	2.5	1.5
Magnesium (Mg)	"	"	0.3	0.4*	0.1
Zinc (Zn)	mg/kg	dm	106	1700**	80
Lead (Pb)	"	"	30	180**	10
Cadmium (Cd)	"	"	0.8	6.0**	0.2
Mercury (Hg)	"	"	0.3	6.0**	0.04
C/N ratio (org. N)			14.2	8.8	23.2

* means value of 25 Swedish sewage plants

** means value of 90 Swedish sewage plants, in cooperation with S. Oden

From Valdmaa (1974)

it rapidly removes human waste from the home, dilutes and distributes it, causing pollution and contamination of our natural water resources. On the other hand, retention of human wastes with their potential populations of pathogenic bacteria and viruses within the home, can only be considered safe and sanitary if they are truly isolated from the home environment. Still to be determined is the question of whether or not vectors such as flies and other insects can truly be isolated from the stored wastes. Although some of the manufacturers claim that the humus produced by the units is safe for disposal in flower beds and gardens, it remains to be proven whether units which are continually receiving pathogenic organisms can produce a product which can be disposed of without special precautions. Even if some

TABLE 4. PRESENCE OF BACTERIA IN TOILET COMPOST SAMPLES

Toilet	No. of bacteria/g air-dry sample		
	Total 22°C	Total coliform 35°C	Thermostable coliform 44°C
1	$4.2 \cdot 10^5$	$1.0 \cdot 10^2$	10
2	$3.0 \cdot 10^7$	10	10
3	$1.2 \cdot 10^5$	10	10
4	$6.3 \cdot 10^5$	$2.0 \cdot 10^2$	10
5	$2.7 \cdot 10^5$	$1.0 \cdot 10^3$	$1.5 \cdot 10^3$
6	$1.2 \cdot 10^7$	$1.0 \cdot 10^2$	10
7	$3.5 \cdot 10^6$	$3.2 \cdot 10^5$	$2.74 \cdot 10^5$
8	$6.2 \cdot 10^6$	$7.0 \cdot 10^5$	$5.0 \cdot 10^5$

From Valdmaa (1974)

of these questions cannot be positively answered, can composting toilets contribute to sanitation when compared with present practices such as the use of "honey bags"? Questions such as these need to be completely answered before widespread adoption of these units can be fully endorsed.

Before the small composting toilets can be accepted, even as an interim solution to human waste disposal in northern communities, a number of problems with the existing units will have to be overcome. Since the units are very sensitive to the solid and liquid loading rates, and especially shockloading, provision of a larger composting compartment or a better method of controlling moisture content is required to ensure that the units will operate under wide variations in loading without turning septic or drying out. The small units presently on the market are sized for a family of three or four persons. Many families are much larger than this and would quickly overload a single unit. While the small size is desirable for installation and

space requirements, the small units require auxiliary heating to speed up the composting process and to evaporate the excess moisture received as urine. With power costs in most northern communities being very high, the cost of operating such units is likely to be burdensome.

The aesthetics and sanitary qualities of the present units leave much to be desired. Although the waste is quite rapidly decomposed, it is accessible to flies and other vectors each time the toilet cover is opened. The close proximity of the waste to the toilet seat opening is also aesthetically offensive. When operational problems occur and the compost becomes septic, odors from the compost seep into the home environment in spite of forced draft ventilation systems.

Finally, the difficulties being experienced by various researchers on units placed with selected families in experimental programs show that if the units were to be distributed in volume to northern communities, major problems would be experienced in keeping the units maintained and operating properly.

FUTURE TRENDS IN TOILET TECHNOLOGY

A review of toilet technology has indicated that the ideal system for use in cold climates has not yet been developed. Following the criteria given by Alter, it is postulated that an ideal unit could have the following characteristics:

- a. It would fall in the dry treatment category of systems.
- b. It would be mechanically simple and have low power requirements.
- c. The treated waste would be sanitary and would be able to be disposed of easily without endangering the fragile northern environment.
- d. The device would require little or no maintenance except for periodic removal of treated waste and cleaning.
- e. The process would be aesthetically and sanitarily acceptable.

- f. The device would have a mechanical method of removing the waste from the receiving receptacle and transferring it into an isolated treatment system.

Although such a toilet system does not at present exist, the concepts and methods are available to make such a system a reality. The composting process will allow the treatment of waste to take place without removing the waste from the building in which it is produced. If properly designed, the composting process requires little or no energy input, and the waste is reported to be transformed into a sanitary and environmentally harmless product. If a simple sanitary system of mechanically transferring the waste from the receiving receptacle to the composting unit were to be developed, a toilet system could be created which would meet all the criteria necessary for northern use.

APPENDIX - TOILET SYSTEMS

DRY STORAGE AND REMOVAL SYSTEMS

Privy Chamberpot

General description: The privy chamberpot system is the oldest and simplest method of handling human waste. Waste is either deposited directly in the privy or transferred to the privy via the chamberpot or honey pail.

Northern application: While privies are a safe and acceptable method of handling human waste, the aesthetics of use during cold weather leave much to be desired. The conventional pit privy is not viable in permafrost regions where the pit is difficult to dig, and once dug acts only as a storage pit with little or no opportunity for liquid to leach away. Once a privy pit is dug in permafrost, it may cause permafrost degradation.

Costs: Very low.

Power requirements: Privies have no power requirements.

Advantages: The pit privy removes the waste from the dwelling and if

properly constructed provides a safe and acceptable method of disposal. It requires no water or power.

Disadvantages: The pit privy has a short life in arctic areas and leaves much to be desired with respect to comfort and aesthetics.

References: Alter (1973), Nimpuno (1976), Rybczynski *et al* (1973).

Honey Bags and Bucket Toilets

General description: The most common method of handling human waste in northern homes lacking piped services is the honey bag in combination with a bucket toilet. A simple bucket toilet is located within the dwelling. The bucket is innerlined with a plastic bag. When the bag capacity is reached, it is manually removed and replaced with a new bag. Honey bags are manually collected and transported by a collection vehicle to a disposal area, usually at or near the local dump or lagoon site.

Application to the north: In most communities where economic and permafrost conditions make installation of piped systems impractical, the honey bag has become the most common method of handling human waste.

Cost: Although the capital cost for the individual unit is low, the cost of the collection vehicle and roads make the overall capital costs of honey bag systems high. Operational costs are high because of the labor intensive nature of bag collection and the operational cost associated with collection vehicles in northern areas.

Power requirements: Power requirements for each individual unit are nil, however, fuel requirements for collection vehicles in arctic areas may be significant.

Advantages: The bucket toilet-honey bag system is adaptable at low unit cost to almost all situations in the arctic as long as a pickup service can be initiated. It is aesthetically acceptable as long as frequent removal of used bags is made. It allows the toilet to be located indoors.

Disadvantages: The honey bags constitute a major source of infection in northern communities. The bag contents are often spilled during collection and contamination of the soil in the community is common place. Once collected, disposal of honey bag contents without further health hazards and damage to the environment remains a problem. The toilets leave much to be desired from a sanitary point of view since the wastes are stored in concentrated form within the dwelling. Flies and odors make the toilets aesthetically unpleasant, especially if collection is irregular and decomposition of bag contents begins in the home.

References: Alter (1974), Alter (1973), Deans and Heinke (1972), Heinke (1974).

Packaging Toilets

Description: The packaging toilet is basically a bucket toilet with a packaging mechanism. Waste is received in a plastic tube which is heat sealed after each use to form a series of "sausages". The "sausages" are collected in a bag beneath the floor of the toilet unit. Each time the toilet is used, the waste is sealed, odors are contained and flies and other vectors are isolated from the waste. Ease of handling is improved, and breakage of bags is minimized by isolated small quantities of waste in separate "sausages".

Application to the north: The packaging toilet should have immediate application in northern homes as an alternative to the standard honey bag system.

Capital and operation costs: Capital cost of a packaging toilet is quite a bit more than a standard bucket toilet (\$500 - \$1000) but it is still below the cost of most waterborne systems. Operating costs are limited to purchase of plastic tubing for packaging the waste. Waste collection costs would be similar to those encountered with the standard honey bag.

Power requirements: A small amount of electric power is required to

operate the heat sealing mechanism.

Advantages: The packaging of the waste seals it off from the home environment, stopping odors and preventing any spread of pathogens. The packaging of the waste into small parcels should also help prevent breakage when the waste is subsequently handled during removal to its final disposal site.

Disadvantages: Packaging of the waste into airtight sausages will effectively isolate it for a limited time period. Anaerobic decomposition with the waste will eventually produce gas and break the sausage container if the waste is not disposed of in a reasonable length of time. The additional plastic in the wrapping would interfere with subsequent handling of the waste if treatment of concentrated wastes were to be carried out at the community rather than the usual disposal at a dumping site.

References: Nimpuno (1976), Rybczynski *et al* (1973).

Freezing Toilets

General description: The development of the freezing toilet has markedly improved the aesthetics and sanitation of holding concentrated human waste within the dwelling. A number of models are now on the market in the Scandinavian countries. The basic principle is to place a toilet seat above a small freezing compartment; the waste falls into a plasticized bag where it is frozen and stored at temperature of approximately -20°C . The low temperature prevents decomposition, stops odors, and makes handling of the waste much easier and more acceptable than in the case with the standard honey bag. Comfort of use is maintained by directing heat from the compressor to the toilet seat to keep it warm.

Application to the north: The freezing toilet would seem to have immediate application in northern homes presently serviced by honey bags and would provide a more sanitary and aesthetically acceptable method of handling human waste.

Cost: The cost of a freezing toilet is higher than for a bucket toilet

but much lower than most other systems. Operating cost of the unit is low; however, costs for collection and disposal of the waste would be similar to "honey bag" systems.

Power requirements: The small size of the units keep electrical requirements low with a current draw of less than 150 watts during operation of the compressor.

Advantages: The storage of the waste in a frozen state has great sanitary and aesthetic advantages. The waste does not begin to decompose. Odors are reduced or prevented. Flies and other vectors are not attracted to the waste. In cold climate areas, it may be possible to stockpile the waste outside the homes during periods of bad weather without having problems of bags freezing together.

Disadvantages: Freezing toilets, while providing a relatively sanitary and aesthetically acceptable method of managing human waste within the home or building, do not aid in the handling or disposal of waste unless it is handled while still in the frozen state.

General comments: The freezing toilet should be evaluated in a northern community on a trial basis to determine the degree of improved sanitation and to assess the operating and maintenance costs.

References: Nimpuno (1976), Rybczynski *et al* (1973).

LIQUID BORNE STORAGE AND REMOVAL

Holding or Pumpout Tank Systems

General description: The holding tank or sewage pump out tank takes the place of the sewer connection by receiving and storing liquid waste until it can be collected by a pumpout vehicle. The holding tank allows the installation of normal plumbing fixtures in areas where centralized sewer systems are unavailable and soil disposal of an effluent is impractical. Holding tanks are often combined with low water use toilets to minimize the quantity of wastewater produced and, thus, the frequency of waste collection required.

Application to the north: Holding tanks are a practical solution to

providing water conveyed waste disposal for homes in arctic communities lacking sewer and water systems.

Costs: The capital cost of providing holding tanks is much lower than for a central sewage system. Balanced against the low capital cost, is the high operating cost caused by the need for frequent pump out of the holding tank contents. In northern communities this cost may be as high as 3¢ per gallon. Servicing costs for pump out systems using conventional water closets may become prohibitive.

Power requirements: Power requirements for the holding tank are low depending on heating requirements. The power requirements for the collection vehicles is significant in northern areas.

Advantages: Holding tanks allow the installation of water borne waste disposal systems in areas where centralized sewer systems and effluent discharges are impractical.

Disadvantages: The major disadvantage is the need for frequent pump out of the tanks and the cost of such service. Some spillage of sewage resulting in contamination of the surrounding soil is common during the disengagement of the pump out hose.

References: Alter (1973), Deans and Heinke (1972).

Chemical Toilets

General description: Chemical toilets use strong caustic solutions to stabilize human waste. The basic configuration is to receive the waste in a holding tank charged with a strong lye solution. The high pH of the chemicals solubilizes the waste, destroys bacteria preventing decomposition, and to some extent, reducing odors. Chemical toilets come in many configurations, the simplest being, a vented tank with a toilet seat positioned on a drop pipe directly above the tank so that waste falls directly into the tank. Once the tank becomes filled, it is emptied and a new charge of chemicals is placed in the receiving tank.

A variation of the chemical toilet is the recirculating chemical toilet. In this case, the tank is not necessarily positioned

directly beneath the toilet bowl but can be connected via piping. The toilet is flushed, using the tank contents as a flushing agent. Either manual pumping or a small electrically operated pump returns the flushing fluid to the toilet bowl.

Application to the north: Chemical toilets have been used in many northern communities and provide an acceptable alternative to other toilet systems when water supply is lacking and waste disposal is a problem.

Costs: The chemical toilet has a moderate capital and operating cost.

Power requirements: Chemical toilets, in general, do not require power. Units equipped with an electrical pump require a small amount of electricity.

Advantages: The chemical toilets provide a relatively sanitary way of holding human waste. If properly charged with chemicals, the bacteria in the waste are destroyed and decomposition of the waste is stopped. The water requirements are low. Operating costs are generally lower than for water borne systems.

Disadvantages: Aesthetics and sanitary aspects are better than for septic toilets or honey bags but do not compare with water borne systems. Chemical toilets must be emptied and recharged at intervals. While emitting less odors than toilets holding untreated wastes, some odors are emitted. The waste must still be disposed of in an acceptable manner.

References: Alter (1973), Deans and Heinke (1972), Heinke and Deans (1973).

Vacuum Toilet Systems

General description: Vacuum toilet systems use an air pressure differential to transport waste in a smaller than normal piping system using periodic traps. The self-contained system consists of a vacuum collection tank and vacuum pump coupled to a specially designed low water use toilet. The vacuum or pressure differential allows the

waste to be conveyed in a series of slugs with only a small amount of water to act as a lubricant and sealer between the slugs of waste.

Application to the north: Since vacuum systems allow water conveyance of waste with a minimum of water use, they could have widespread application in northern communities where water supply and sewage disposal present problems. The ability of vacuum systems to transport wastewater against gravity make them useful for homes having their holding tank located on the main floor.

Cost: Vacuum systems are relatively expensive costing approximately \$1,500 for each toilet system. Costs for water supply and wastewater collection from the holding tank are minimized due to the savings in water used and sewage produced.

Power requirements: Power requirements of the vacuum system are moderate.

Advantages: The vacuum system minimizes water use and allows holding tanks to be located on the same floor level as the toilet.

Disadvantages: The major disadvantage to vacuum systems is their cost. Vacuum systems are rather complex mechanical systems which may require more maintenance than several of the other types of systems available.

References: Averill and Heinke (1974).

Non-Aqueous Flushing Systems

General description: The scarcity of water for flushing and the problem of effluent disposal has led to the development of systems which use a non-aqueous fluid for toilet flushing. Non-aqueous systems generally use an oil base flushing fluid to remove the excreta and urine from the toilet to a settling tank where the fluid is separated from the waste, cleaned by filtration and recycled. Most systems combine this type of removal with an incinerator to destroy the collected waste.

Application to the north: If perfected, non-aqueous flushing systems would have obvious application for buildings in the north where water supply and waste disposal constitute major problems. They would be

especially useful in commercial buildings which do not generate much grey water. The inherent deficiencies in the systems and their very high capital and operating costs make their application for single family homes inappropriate.

Costs: These systems are high in capital and operating costs. The fuel for the incinerator, the replacement of lost flushing fluid and the complexity of the systems all contribute to costs that make their application, except for special circumstances, inappropriate for use in northern communities.

Power requirements: Electrical power requirements are relatively low while fuel costs for incinerator operation are high.

Advantages: The non-aqueous system can provide a relatively sanitary and aesthetically acceptable method of handling human waste where limited water supply and effluent disposal definitely rule out the use of water carriage systems.

Disadvantages: The flushing fluid is difficult to keep clean and deodorized. The system requires competent service personnel and the costs are excessive.

References: Mathew and Nesheim (1973).

LIQUID BORNE TREATMENT

Septic Tanks

General descriptions: A septic tank is a large tank which provides for settling of particulates from the sewage and which acts as a low rate anaerobic digester. Most septic tanks use a second compartment which by using a siphon releases the effluent to a tile field intermittently.

The majority of self-contained water borne systems in temperate climates utilize a septic tank coupled with a tile field. In some regions of the prairies where soil permeability is low, septic tanks are combined with ejection systems which spray the septic tank effluent on to the ground surface.

Application to the north: Because of the problem of freezing, septic tanks and tile fields can only be used in northern areas where permafrost is not a problem. Septic tanks and ejection systems may be applied to isolated homes in the north but because the effluent discharged is not disinfected they are unsuitable for use in northern communities.

Costs: Septic tanks and tile fields have a medium capital cost and a low operational cost.

Power requirements: Power requirements for septic tanks and tile fields are nil unless electrical heating is used to prevent freezing of the bed. Septic tanks and ejection systems have a small power requirement to operate the pump and intermittently provide heating to the discharge line.

Advantages: In areas where soil conditions and climate allow them to be used, septic tank systems are the most sanitary and convenient method of providing self-contained service for a single home or building.

Disadvantages: They cannot be used in permafrost areas except for isolated homes where spray ejection on the ground surface is an acceptable practice.

References: Hickey and Duncan (1966), Province of Manitoba (n.d.), Warshall (1975).

Aeration Systems

General description: Aerated biological treatment systems which have long been used as a treatment method for municipal and industrial sewage. Over the years a number of different designs have been marketed or studied for use in single family dwellings. Most home systems use a variation of the extended aeration process in which raw sewage is discharged into an aerated tank with complete mixing. The mixed liquor flows to a second tank or compartment where sludge is separated from the liquid and recycled to the aeration chamber or wasted. The plants generally are designed to have detention time in the aeration

chamber of 24 hours. While these plants, if operated properly, are capable of giving good treatment, they require regular maintenance and servicing.

Application to the north: Although the aeration systems can provide a better quality effluent than septic tanks, the problem of effluent disposal in northern areas restricts their use for individual home treatment.

Costs: Capital costs of most aerated systems are very high (\$2,500 +). Operational costs are also high.

Advantages: Aerated treatment systems are able to provide good treatment and produce a good quality effluent. They may be used to advantage in recycle systems to produce a good quality flushing fluid.

Disadvantages: Aerated treatment systems are costly to purchase and maintain. They are complicated mechanically, requiring in general, a large amount of servicing and maintenance. Except in recycle configurations they still require disposal of an effluent.

References: Deans and Heinke (1972), Rybcynski *et al* (1973), and Smith (1973).

Rotating Biological Contactors

General description: The rotating biological contactor (RBC), is a device that uses a series of partially submerged rotating discs to provide aeration and mixing to the wastewater being treated. A biological film develops on the surface of the discs and through the rotating action of the discs, the film alternatively comes in contact with the liquid being treated and the air above the liquid surface. Recently, this type of waste treatment unit has been used in small configurations suitable for providing treatment for individual buildings or dwellings.

Application to the north: While like most other treatment processes, the RBC can produce a high quality effluent, its use in northern communities is limited by the problem of disposing of the treated

effluent. One possible application is its use for isolated homes in conjunction with an ejection system to dispose of the effluent on the soil surface. It might also be used in a treatment system which recycles effluent for toilet flushing.

Costs: Although RBC's are relatively simple, patents, lack of competition and low sales volume make these systems very expensive to purchase. Operating costs should be low in comparison to other aerobic treatment systems.

Power requirement: Power requirements are lower than most other treatment devices except the septic tank.

Advantages: The RBC unit has advantages over most other aerobic treatment devices in that the mechanism is inherently simple, mechanically requiring only a small motor with a reduction device to power the rotating discs. The servicing and maintenance requirement would be less than for most other treatment systems and could, except for major breakdowns, be handled by a layman or homeowner. The process recovers rapidly from upsets caused by over and underloading and other causes.

Disadvantages: The major disadvantages are capital costs and the problem of effluent disposal. RBC's like other treatment devices require heated space which limit their application to new construction designed with space for a treatment system.

Variations: Possible variations are similar to other treatment systems. Recycle systems have perhaps the most potential for use in northern communities. A possible development is a small recycle RBC unit combined with a toilet for installation within the bathroom of the home.

Physical Chemical Treatment Systems

General description: Physical-chemical treatment systems are systems which chemically flocculate the solids in the sewage and then remove them by settling and filtration. Smaller systems have been developed for use in the marine industry but systems for use in the individual home have not been marketed to any extent to date.

Northern application: Physical-chemical systems are in general complicated to operate and require costly chemical additions. Except in a recycle

form they require effluent disposal and as such are unsuitable for most northern applications.

Costs: Physical-chemical treatment systems, if available, would be expensive to purchase (\$3,000) and costly to operate because of the requirements for chemicals such as lime, alum and activated carbon.

Power requirements: Power requirements for a home size unit would be moderate. Power would be needed to operate pumps and the chemical addition equipment.

Advantages: Physical-chemical treatment systems are able to produce good quality effluents which make them attractive for use in recycle systems. Because they do not rely on biological breakdown, they are able to provide a consistent treatment under changing wastewater conditions.

Disadvantages: Physical-chemical systems are mechanically and technically complicated. They would require technical expertise to install and regulate them. They would be costly to purchase and operate.

DRY TREATMENT SYSTEMS

Incinerating Toilets

General description: Incinerating toilets utilize auxiliary power to dry and incinerate waste. A number of models are available which utilize a variety of energy sources including electricity, propane and natural gas. The toilet seat is located above a combustion chamber which is usually lined with a special paper insert to receive the waste. Following use of the toilet, the combustion cycle is initiated and the waste is dried and incinerated, leaving only an ash to be removed. Most models utilize a fan to exhaust the combustion gases and provide air for burning.

Application to the north: The units are being used at isolated posts in northern Canada. The high capital and operating costs and the odors produced during incineration make them undesirable alternatives for general installation in northern communities.

Costs: Capital costs are not excessive; however, the high cost of fuel and electricity in northern areas make operating costs of the incineration toilet higher than any other system.

Power Requirement: Power requirements of the incinerating units are very high. Electric units use approximately 3,000 - 4,000 watts during the incineration process which lasts approximately 45 minutes. Incineration is normally carried out after each use.

Advantages: Incinerator units completely destruct the waste negating the need for collection and disposal. They are completely sanitary.

Disadvantages: The high cost of operation (as high as 50¢ for each use) makes incineration toilets impractical for most northern applications. The incineration cycle produces strong odors which are objectionable when released to the community environment.

Comments: While the capability of the incineration toilets to destroy waste including pathogens in its receiving receptacle make them highly desirable for certain unique situations, the cost of operation make them impractical for most northern applications.

References: Deans and Heinke (1972), Grainge and Slupsky (1973).

Anaerobic Vault Toilets

General description: Anaerobic vault toilets consist of a large vault, topped by a chute and toilet seat. Waste falls directly into the vault where it undergoes slow anaerobic decomposition.

Application to the north: Because of their poor sanitary and aesthetic qualities, their use in homes in northern areas is unacceptable. They have been used in remote parks and other isolated locations where service and maintenance of other conventional systems is not possible.

Cost: Vault toilets have a medium capital cost and very low operating cost.

Power requirements: Vault toilets have no power requirements, except when heat is required to keep them from freezing.

Advantages: Vault toilets provide a minimum of service where other systems requiring regular service and maintenance are impractical. They require no water, power, and very little service.

Disadvantages: Vault toilets produce strong odors and are unsanitary.

Composting Toilets

General description: Composting toilets use aerobic microbial action to break down the waste which is received "dry" in the composting compartment. Successful composting toilets are of two types:

- a. a large inclined slope container located beneath the bathroom which receives the waste via a toilet chute; and,
- b. smaller units which sit on the bathroom floor and have the toilet seat on top of the composting chamber.

The larger units generally use natural convection and self-generated heat to evaporate excess liquid and carry out the composting action. The smaller units utilize auxiliary heating and forced convection of air to carry out the composting process rapidly.

Application to the north: Composting toilets may find wide application in the north, once the technology has developed to the point that units are available which will provide sanitary and aesthetic disposal of human waste without major operational problems.

Costs: Costs of the larger units are high, approximately \$1,500 to \$2,000 without including installation costs. The small electrical units are in the medium price range (\$500 - \$1000). Operational costs of large units are low. Electrical costs for small units are likely to be significant at northern electrical rates.

Power requirements: Most of the small composting toilets require auxiliary heat. Of the electrically heated units reviewed, the maximum power usage ranged from 1.2 to 8.75 kilowatt hours per day. While most of the units are thermostatically controlled, power usage could be very significant in northern homes which are poorly heated. The larger units are generally designed to function without auxiliary heating, however, unless installed in a heated area such as a warm basement, auxiliary heating is necessary.

Advantages: Composting toilets provide a reasonably sanitary method of handling toilet wastes without sewer systems or collection vehicles.

Disadvantages: The present units have operational problems and are not as sanitary or aesthetically acceptable as most water borne systems. The high cost of power in northern communities could make the operation of the smaller units quite expensive.

References: Nimpuno (1976), Norwegian Consumer Council (1975).

BIBLIOGRAPHY

Alter, A.J. (1973). The polar palace. The Northern Engineer, 5, 2, 4.

Averill, D.W. and Heinke, G.W. (1974). Vacuum sewer systems. Northern Science Research Group, Department of Indian Affairs and Northern Development, Ottawa.

Ekland, L.T. (1974). The non-flush toilet is possible. Water and Pollution Control, 112, 2, 18.

Flood, G.M. (1926?). Dry-closet systems. Sewage Disposal From Isolated Buildings. The Sutherland Publishing Co., Ltd., Manchester, G.B.

Grainge, J.W. and Slupsky, J.W. (1973). Toilet units for northern communities and workcamps. Supplementary Report D, Management of Waste From Arctic and Sub-Arctic Work Camps. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report No. 73-19.

Hanks, T.G. (1967). Solid waste/disease relationships, a literature survey. U.S. Public Health Service, Department of Health, Education and Welfare, Cincinnati, Ohio.

Heinke, G.W. (1974). Preliminary report on disposal of concentrated wastes in northern areas. Arctic Waste Disposal, Environment-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Report No. 74-10.

Heinke, G.W. (1973). Solid waste disposal in communities of the Northwest Territories. Solid Waste Management, Environmental Protection Service, Department of the Environment, Ottawa.

Heinke, G.W. and Deans, B. (1973). Water supply and waste disposal for Arctic communities. Arctic, 26, 2, 149.

Hickey, J.L.S. and Duncan, D.L. (1966). Performance of single family septic tank systems in Alaska. Journal Water Pollution Control Federation, 38, 8, 1298.

Love, S. (1975). An idea in need of rethinking, the flush toilet. Smithsonian, 6, 2, 61.

Lindstrom, C.R. (1973). The Clivus-Multrum system: composting of toilet waste, food waste, and sludge within the household. IN: Water Pollution Control in Low Density Areas, Proceedings of a Rural Environmental Engineering Conference, University Press of New England, Hanover, New Hampshire.

✓ Matthew, F.L. and Nesheim, E.E. (1973). Demonstration of a non-aqueous sewage disposal system. U.S. Environmental Protection Agency, Washington, D.C.

McKernan, M. (1975). Personal communication. Consultant to Manitoba Department of Northern Affairs, Winnipeg.

Nimpuno, K. (1976). A study of excreta disposal solutions for the remote north of Manitoba. Unpublished draft report prepared for the Planning Secretariat of the Manitoba Cabinet, Winnipeg.

Norwegian Consumer Council (1976). 21 biological toilets, composting toilets for cottages and pleasure retreats. Forbruker-Rapporten Nr 10 (Consumer's Report No. 10).

Province of Manitoba (-). Home sewage disposal systems. Department of Mines, Resources and Environment Management, Winnipeg.

Rodale, R. (1971). Goodbye to the flush toilet. Compost Science, 12, 6, 24.

Rybcynski, W. and Ortega, A. (1973). Stop the five gallon flush: a survey of alternative waste disposal systems. The minimum Cost Housing Group, School of Architecture, McGill University, Montreal.

Smith, G.E. (1973). Economics of water collection and waste recycling. University of Cambridge, Department of Architecture. Working Paper No. 6.

University of California (1953). Reclamation of municipal refuse by composting. Sanitary Engineering Research Project. Tech. Bull. No. 9, Series 37, Berkeley.

Valdmaa, K. (1974). The Mullbänk toilet. Compost Science, 15, 5.

Warshall, P. (1975). Septic tank practices: a primer in the conservation and re-use of household wastewater. Mesa Press, Bolinas, California.

SESSION IV

EQUIPMENT AND MATERIALS

INSULATED AND HEAT TRACED POLYETHYLENE PIPING SYSTEMS:
A UNIQUE APPROACH FOR REMOTE COLD REGIONS

by

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INTRODUCTION

Objective

The objective of this paper is to describe one method for increasing the reliability and decreasing all costs of water and sewer systems in remote cold regions.

The insulated piping system to be described is commercially available, thus this paper is directed to those currently involved in the design, installation and operation of utilities in these regions. There is also a wide range of industrial applications for this system; however, these are beyond the scope of the paper.

General

During the past few years there has been an increased demand for new and up-graded water and sewer utility systems in northern or remote cold regions. This demand has been spurred by the upsurge in resource development and also by a demand for higher standards in existing systems.

When considering these regions, the designer is faced with the two unique problems, one being the harsh environment and the other the lack of experience upon which to draw. In addition to the design criteria common to southern installations, there are special criteria for these northern areas. In total, these criteria can be divided into two categories, those relating to the function of the system and those relating to the environment in which the system operates. It is in this latter category that the designer faces his greatest challenges.

Ideally, all pipelines should be buried so as to improve local aesthetics, reduce heat loss, prevent mechanical damage, increase vehicle mobility and improve grades (for sewer systems). If the pipe is buried deep enough, in non-permafrost areas, there may not be a need for insulation.

However, deep burial generates a whole set of its own problems and in addition geography limits the use of this technique to areas where the soil temperature in the pipe zone remains above freezing. Shallow burial is a much more attractive alternative, in terms of minimal soil disturbance, ease of installation and maintenance, reduced cost and so on. However, the environmental conditions to which the system is subject are more extreme and such a system will only work if it meets a combined soil, pipe and insulation design criteria.

Historically, most utilities were placed above ground. Utilidors have been, and are still used for the purpose of providing insulation, support and accessibility for such systems. However, they are generally high in installed costs, expensive to maintain, and are subject to mechanical damage and to vandalism. They must be designed for the most extreme temperature variations. Utilidors also tend to impede vehicle movement. They have demonstrated their ability to provide a service but at a relatively high price.

Thus there has been a need for a system that would meet all of the service requirements, be simple and relatively inexpensive to install and operate and be capable of shallow burial wherever possible. At the same time, the design had to be adaptable to above ground or on-pile installations wherever required by specific conditions. Until recently, the development and use of such a system was restricted by the lack of good pre-insulating and jacketing techniques and capable heat tracing technology.

One solution to this problem has been the development of a highly reliable system, assembled and distributed by a single supplier, Du Pont of Canada Limited. The system consists of a core of high density polyethylene pipe, factory insulated with polyurethane foam and jacketed, and incorporating a constant watt per foot heat tracing cable in a channel integral with the pipe. This product package, which also includes field installation services, has undergone several years of successful operating experience. The system and its major elements are described in the following sections.

THE SYSTEM

General

The problem of designing utilities for use in northern or remote cold regions was stated in a very general manner. Some of the specific design requirements are listed in Appendix 1. If a proposed system is to provide full service in these environments it must meet most or all of these criteria.

The system put forward by Du Pont comprises three basic elements, pipe, insulation and cable, in addition to other items which will be described later in the paper. Figure 1(a) and 1(b) illustrate these main elements, with the system being completed with a high density polyethylene jacket (HDPE) in the former and with a metal jacket in the latter. In each case the illustrations show a cut-away of the system at a pipe-to-pipe butt fusion. When supplied, the ends of each pipe are bare to facilitate joining in the field. Insulation half shells are added after joining and these in turn are covered and sealed with a heat shrink sleeve. Also shown is the integral channel with the electric heat tracing cable in place.

Because of the inherent properties of each of the system components (to be described later) and the manner in which they are combined, the system fulfills the design criteria previously referred to in the following manner:

- Mechanically reliable: Experience has shown no cracking under cold or frozen conditions. It is designed for long term.
- Thermally reliable: To the best of our knowledge all heat traced systems properly installed to date have functioned satisfactorily and no freezing or pipe failure has occurred because of under or over-heating of the cable. Experience has demonstrated two things. One is that the pipe does not split or crack when frozen and the other is that the heat tracing will thaw the pipe once the power is restored.

(Illustrated - butt fusion area)

FIGURE 1

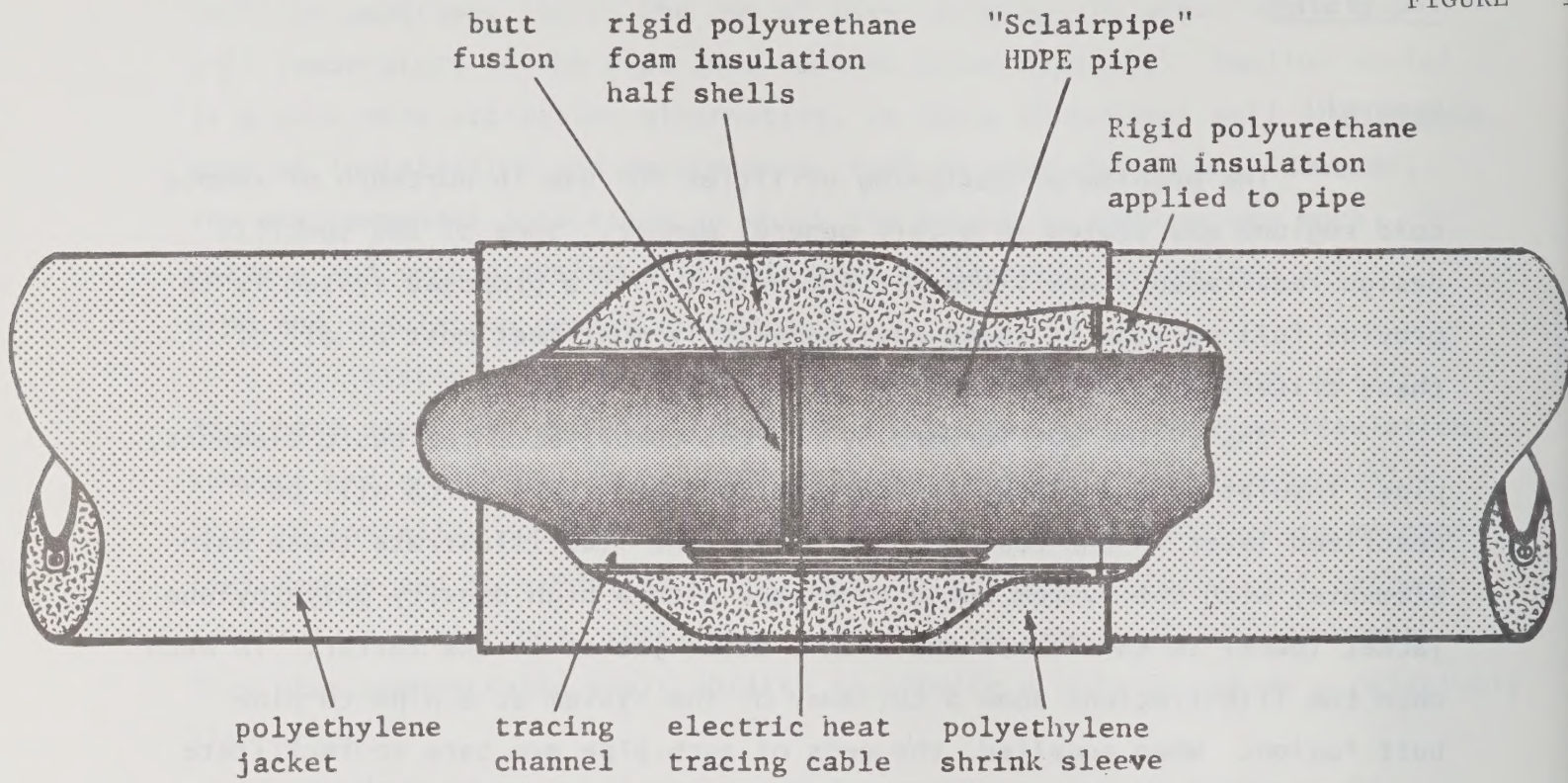


FIGURE 1

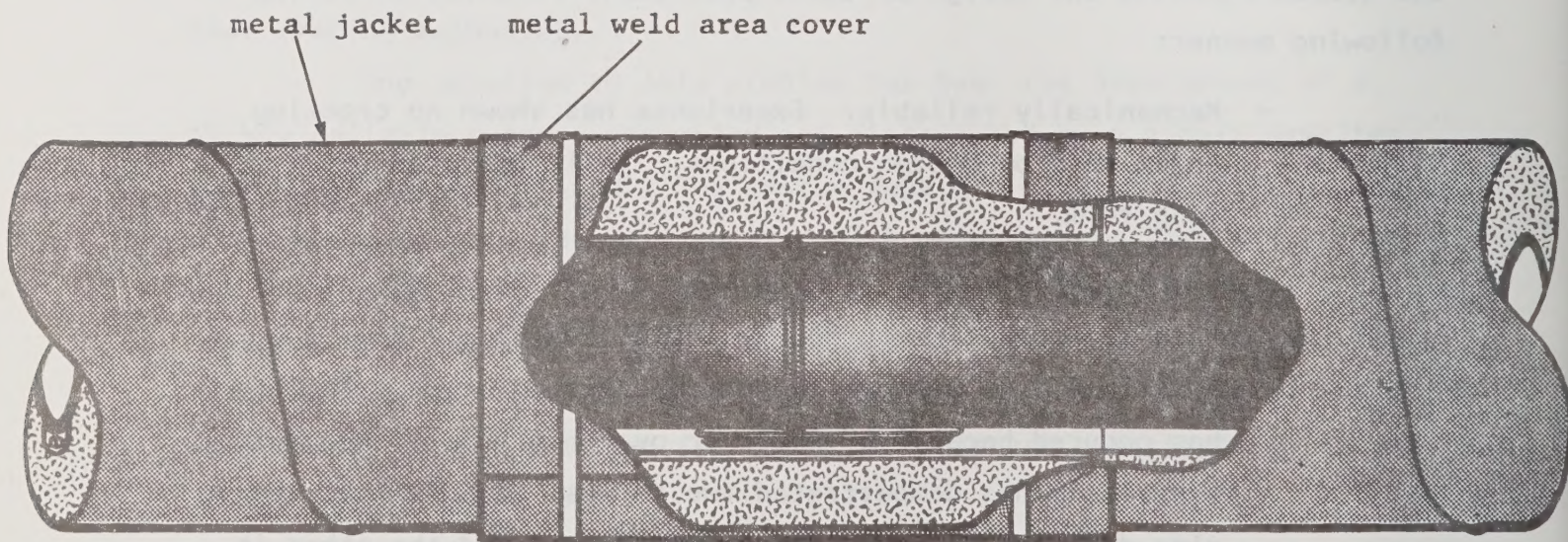


FIGURE 1. BASIC SYSTEM COMPONENTS

- Zero Leakage: Butt fusion joining of HDPE pipe produces a permanent, bottle-tight system. No other system can claim this characteristic, except for welded steel. This eliminates fluid loss which is costly and also damaging to the surrounding environment and to the insulation.
- Flexible: The piping system is able to conform to most movements in unstable soils. This also allows for the elimination of many elbows and thrust blocks.
- Light Weight: For the purpose intended this is one of the lightest piping systems available; simplifying field handling and installation. It is also economical and convenient to ship.
- Ease of Installation: The system lends itself to installation with limited manpower, and the need for special handling equipment is substantially reduced. The butt fusion joining does require one added on-site skill, but this is readily overcome by its high productivity.
- Low operating costs: No maintenance due to leaking joints or cracked, slit pipe caused by freezing. Low power consumption when properly set-up and controlled and low manpower costs to thaw.
- Zero Corrosion.

Basic System Components

The next three sections will describe in general the characteristics of the three main components of the system. The appendix contains a detailed list of these characteristics and a Short Form of Specification in each case.

Polyethylene as a piping material

"Sclairpipe" high density polyethylene pipe (HDPE) has become a standard engineering material for the transmission of water and sewage under pressure as well as for water distribution and sewage collection. These latter two end uses, while not highly developed in southern regions, are of considerable importance in the north.

HDPE pipe combines excellent cold weather handling and performance characteristics with light weight and its unique leak free joining system to provide a balance of properties unmatched by any other piping system. These benefits are of value to the installer as well as the operator of the system.

There has been confusion in the past between HDPE pipe and polyvinyl chloride (PVC) pipe. Both are plastic and are light, smooth and non-corrosive. However, their differences are very significant and it is important that these are clearly indentified. PVC has its best balance of properties at higher temperatures. When cold, PVC becomes brittle and it loses the mechanical durability necessary for handling and installing under such conditions. As well, PVC pipe has bell and spigot joins which cannot guarantee a leak free system. On the other hand, HDPE retains an excellent balance of mechanical properties at low temperatures. It can be handled, fused, bent and it retains impact resistance and ductility when very cold.

Polyethylene pipe cannot be thawed by using it as an electrical conductor. However, this is no longer considered good practice by building codes and alternate methods for thawing frozen service lines exist especially if heat tracing cable is incorporated with the line. A full range of distribution type fittings is not yet available. However, common "off the shelf fittings" can be incorporated through the use of flanges. The existing limited range of polyethylene fittings is presently being expanded.

There are no bell and spigot joints in polyethylene pipe systems at this time. While this is considered a limiting factor in water distribution systems in the south it is actually an advantage in the north where joint leakage cannot be tolerated.

Rigid polyurethane foam insulation, with jacketing

Rigid foamed polyurethane (PU) technology has developed to the point where it can be factory applied to pipe, producing a close cell insulation of uniform consistency with good structural integrity. Two basic coating or jacketing systems are available, one of which is 45 mil HDPE backed by an inner adhesive layer, while the other is galvanized steel. The HDPE jacket is normally used for buried applications where

total watertight integrity is required, while the metal is used for above ground applications. In addition, black HDPE jackets can also be provided for above ground applications. While this jacket is not as tough as the metal it does provide significant advantages in terms of weight and flexibility.

Rigid polyurethane foam has the lowest k value of any commercial insulation and it also combines light weight, high strength with a relative flexibility that closely matches that of the polyethylene pipe itself. One of the distinct advantages is the fact it can be prefabricated in the factory.

Heat tracing cable

The cable used in this system has a two-fold purpose. First, it must prevent freezing in the event of an operating upset, such as a prolonged no-flow condition. Second, it must be capable of thawing the system should it freeze. It is not designed for, nor should it be used as a means of heating the water while flowing. Electrical costs become prohibitive if the cable is incorrectly used in this manner.

In considering freeze-protection, the heat loss under no-flow conditions at 0°C is calculated and the rating of the cable is then chosen so as to compensate for this loss, with appropriate safety factors. In addition, the control system is designed to activate the cable at a set-point temperature above 0°C . To provide a lead time in freeze protection and to allow for variances in temperature detection by thermostats.

Once a cable rating has been initially selected, the rating is then checked to determine if the thaw time is acceptable. If not, a higher rating may be necessary. It is presumed here that the system could freeze if a total power outage occurred for a sufficient length of time. The location of the thaw bulb is also checked. Ideally, it should remain inside the insulation.

Heating cable is required whenever the time to freeze is shorter than the maximum possible shut-down time, where the line cannot be blown clear or drained. Research findings presented at this seminar have indicated that the time to freeze may be as short as the time taken for the water to reach 0°C , and may include the time to lose the heat of fusion.

The cable selected by Du Pont is a parallel resistance type cable having a series of heating zones producing a constant watt per foot output. This heating cable allows for long circuits which can be cut to the required length at point of installation and do not require any special voltage regulation. A significant point is that it does not cause radio frequency interference (RFI), which can be important in remote sites which depend on radio communication.

The cable is backed up by a full range of accessories including thermostat controls designed especially for the core pipe.

SYSTEM LAYOUT AND FEATURES

Generalized System Layout

Figure 2 shows a highly generalized water distribution and sewage collection system layout. While there are many variations of these systems, especially with respect to water distribution the sketch will form the basis for the discussion of individual elements.

This paper is not intended to show the advantages of one layout over another, i.e., single main recirculating versus a double supply and return layout. Rather, it is intended to show how the system described can be utilized to any one of the commonly used layouts.

Double Water Service Line (Recirculating)

Figure 3 shows a typical water service connection using supply and return service lines off of a single recirculating main. It is equally applicable to a supply and return main arrangement. Some of the features to be emphasized are:

- Two service lines, plus a single heating cable are contained in an insulated duct. Refer also to Figure 4.
- The cable is powered and controlled from the house and terminates at the curb stop.
- The duct is joined and sealed using heat shrink sleeves. The joint is completed using insulation half-shells and a second shrink sleeve.

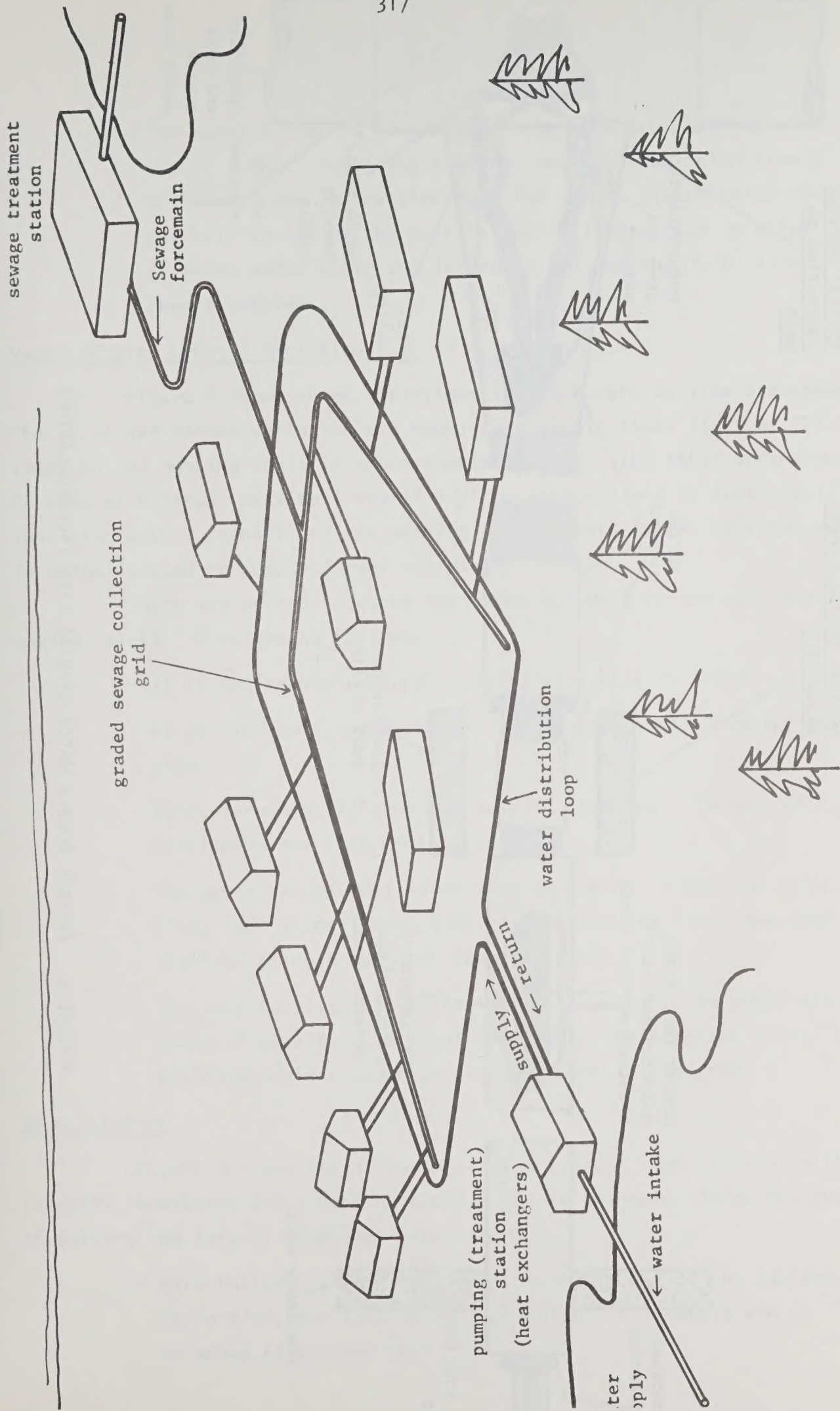


FIGURE 2. COMMON MODERN WATER DISTRIBUTION AND SEWAGE COLLECTION SYSTEM FOR COLD CLIMATES

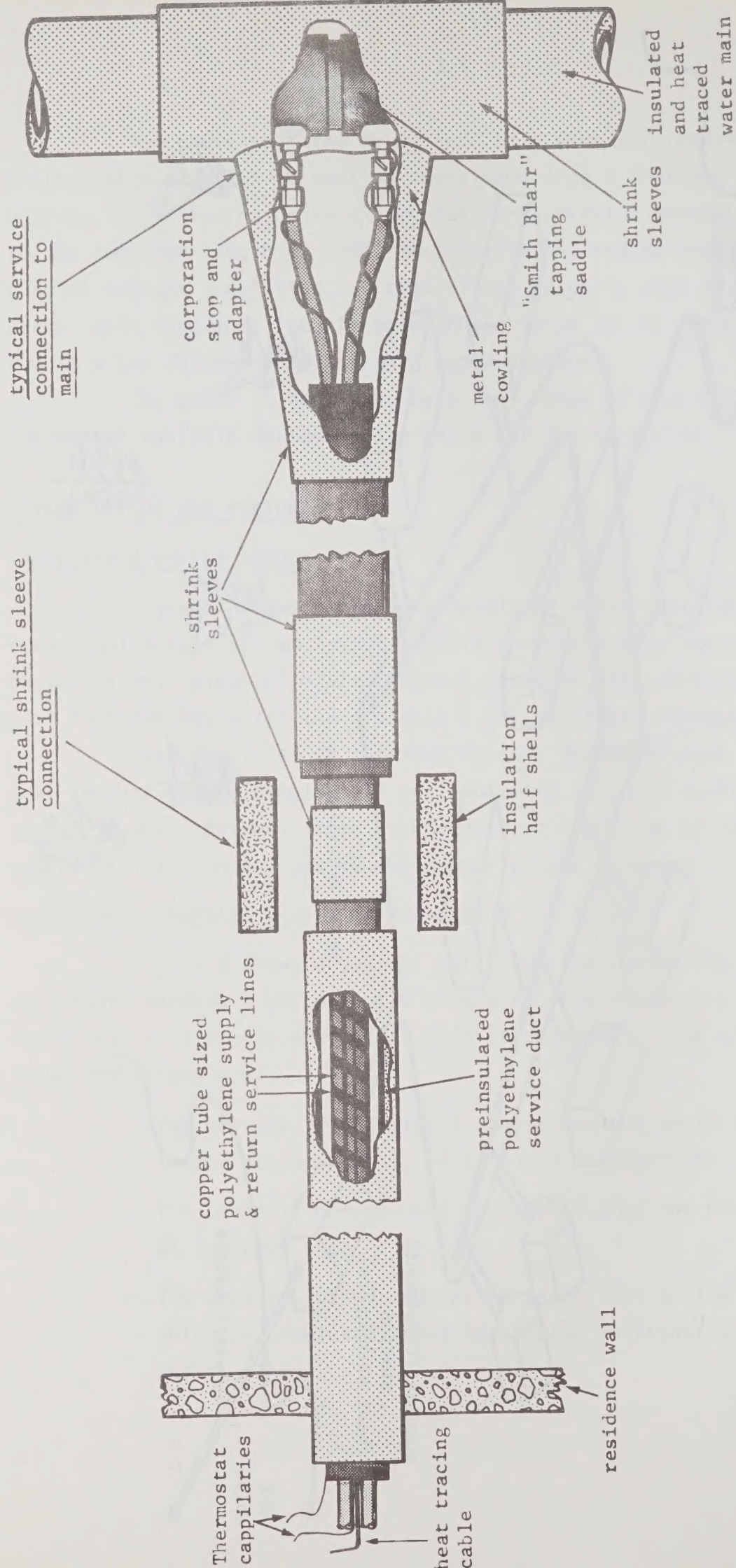


FIGURE 3. TYPICAL DOUBLE WATER SERVICE LINE (RECIRCULATING)

- The service duct is connected to the main line insulation by use of a "kit" involving a metal cowl, insulation (loose or foamed) and shrink sleeves. The shrink sleeve which covers the half-shells on the main is specially designed to allow it to be added after the lateral lines and the "kit" have been assembled.

Water Service Lines - Variations

Figure 4 shows three variations in water service line arrangement. The first and second variation are double and single lines (3/4" or 1") taped to the heating cable in a pre-insulated duct. The third arrangement is used with larger service lines (1 1/2" or greater) and is individually insulated with a channel for the heating cable. This latter service system is normally used to supply larger buildings.

There are several reasons for using the duct system with the smaller pipes. They are as follows:

- It is desirable to supply the service pipe in coils.
- It is difficult and expensive to insulate small diameter coiled pipe.
- Short irregular lengths are usually involved. The use of coils eliminates any intermediate joining.
- The cable can be applied on-site by taping it and the service pipes into a continuous length. The service lines are then inserted through the duct and cut to fit.
- The duct facilitates replacement or repair of the pipes and cable if necessary, without digging up the complete line. Only a single small excavation near the main is required.

Sewer Lateral

Figure 5 shows the arrangement of a typical sewer lateral with integral insulation and a heating cable within a channel. Three methods of joining the lateral pipe are illustrated:

- Butt-fusion. This is a simple method to use if the equipment is on-site, but this is not convenient if laterals are to be added at a later date.

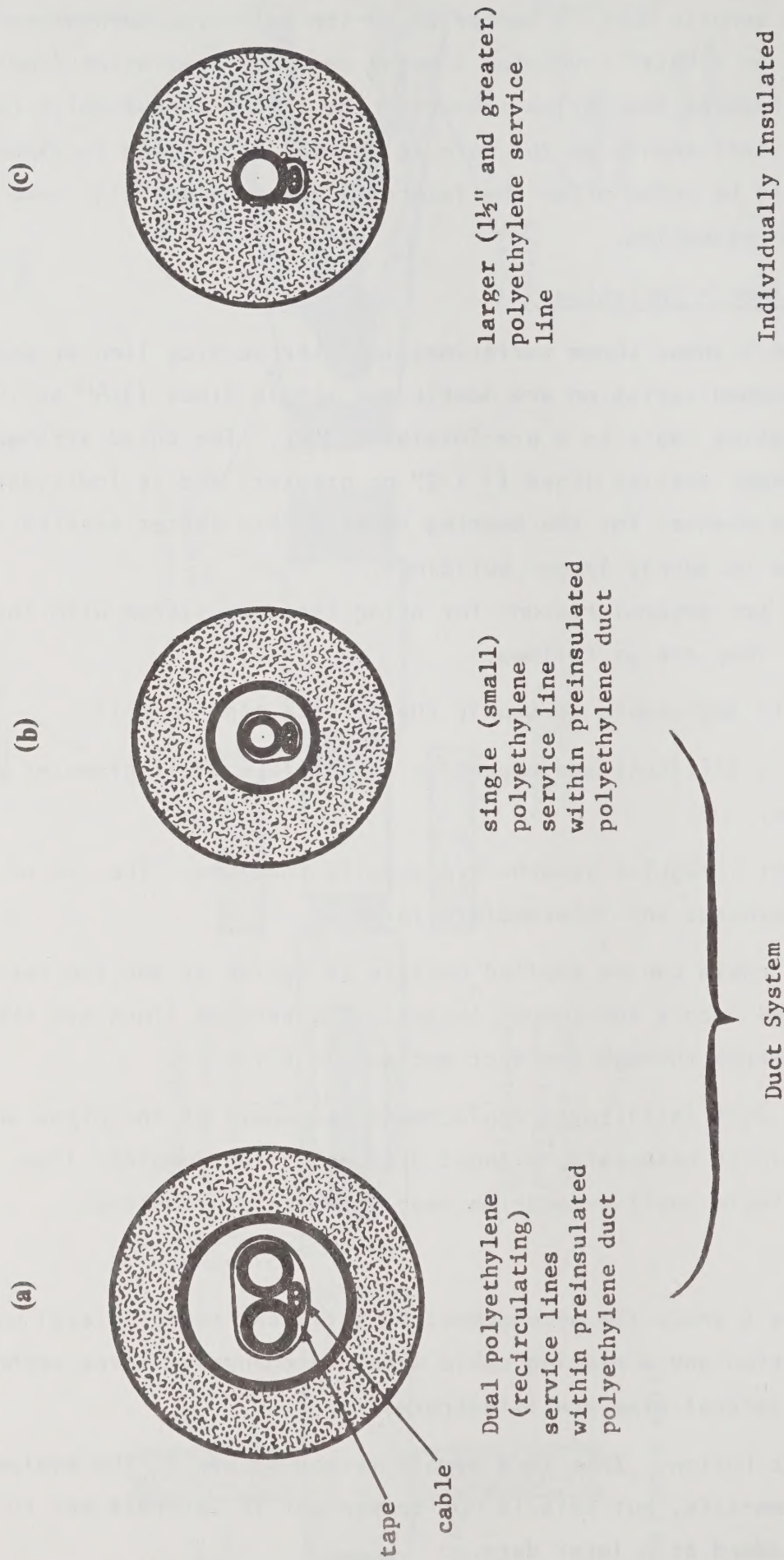


FIGURE 4. WATER SERVICE LINE VARIATIONS

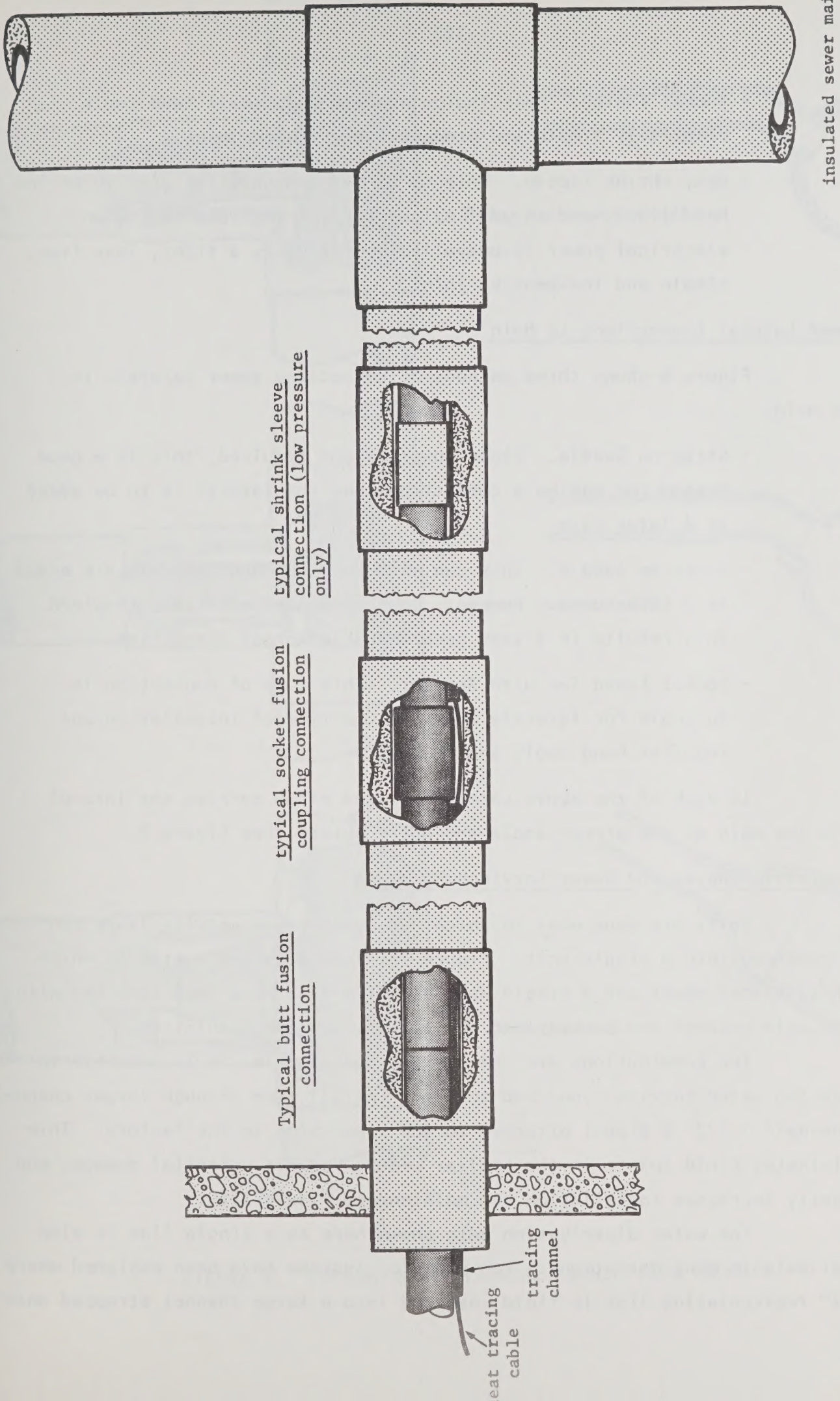


FIGURE 5. TYPICAL SEWER LATERAL

- Socket fusion. This fusion process uses small hand tools, is relatively simple and produces very rugged joints.
- Heat shrink sleeve. This is to be used only for gravity or low head lines, and is well suited for joining laterals when electrical power is unavailable. It gives a tight, leak free, simple and inexpensive joint.

Sewer Lateral Connections to Main

Figure 6 shows three methods of connecting sewer laterals to the main.

- Strap-on Saddle. Since power is not required, this is a good method for making a connection when the lateral is to be added at a later date.
- Fused-on Saddle. This can also be done when laterals are added at a later date. However, power and hand tools are required. This results in a very secure and leakproof connection.
- Socket Fused Tee with Reducer. This type of connection is suitable for laterals added at the time of installation and requires hand tools and power.

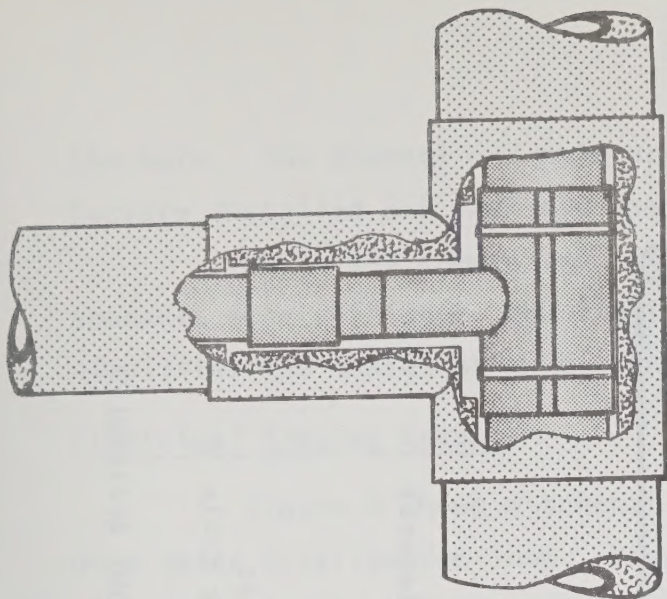
In each of the above cases, a mitred elbow carries the lateral into the main at the proper angle and entry point. See Figure 6.

Combination Water and Sewer Services Packages

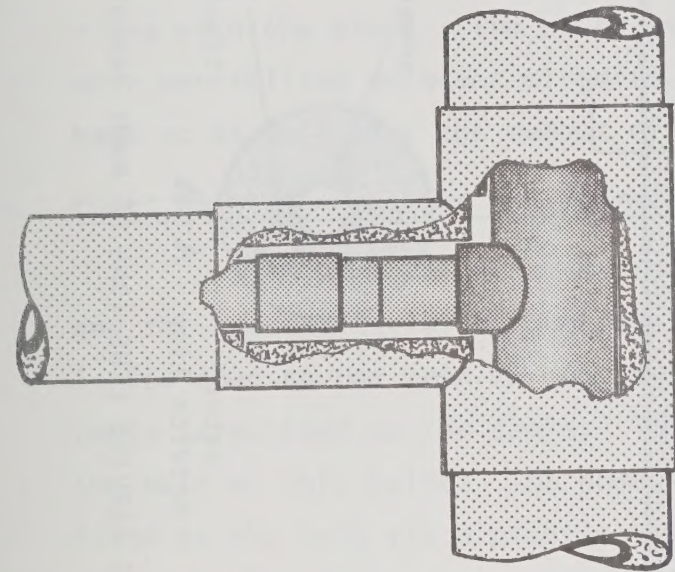
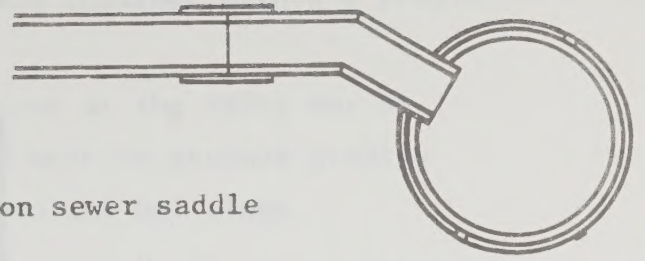
There are many ways in which water and sewer service lines can be combined into a single unit. Figure 7 illustrates one system in which a heat traced sewer and a single water service line have been combined with the cable channel and locked into the factory applied insulation.

The combinations are unlimited. For example, it is possible to have two water service lines and to field install them through larger channels (one-half 1 1/2" Ø pipes) attached to the sewer pipe in the factory. This eliminates field joints in the smaller pipes, reduces potential damage, and greatly increases installation and maintenance flexibility.

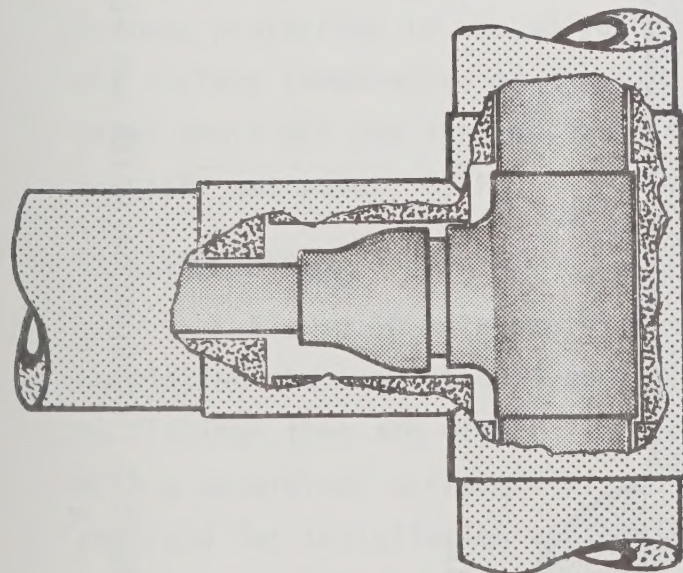
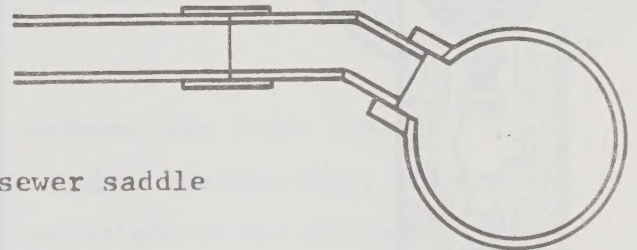
The water distribution main shown here as a single line is also available in many variations. For example, systems have been designed where a 2" recirculating line is field inserted into a large channel strapped onto



Strap on sewer saddle



Fused sewer saddle



Reduced tee

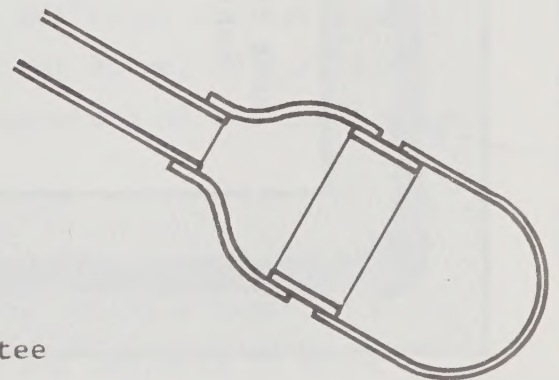


FIGURE 6. TYPICAL SEWER LATERAL CONNECTIONS TO MAIN

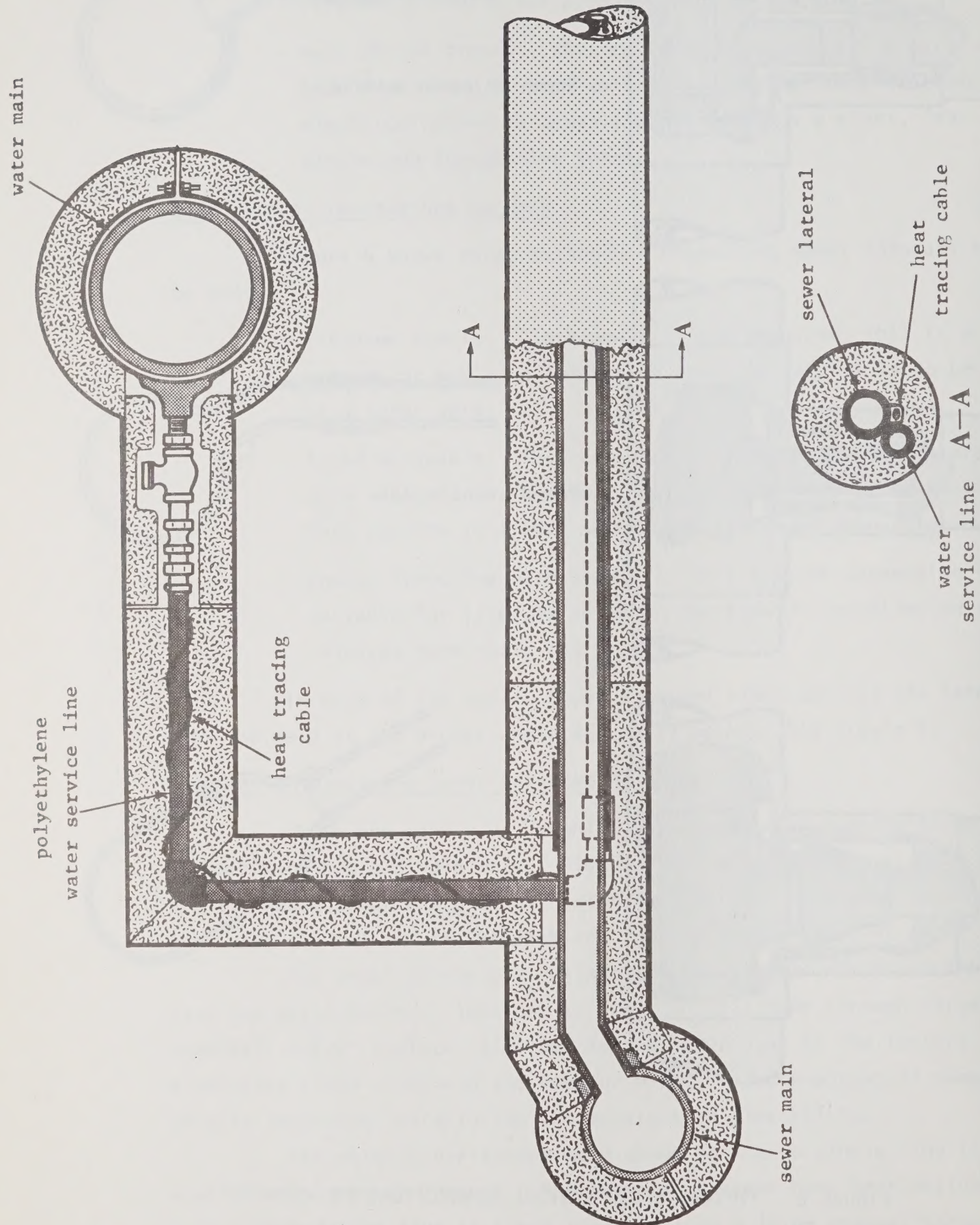


FIGURE 7. COMBINATION WATER AND SEWER SERVICE LINE (ONE OF MANY VARIATIONS AVAILABLE)

the main. The channel and main are both locked together within a single, factory installed and jacketed insulation.

While the completion of the insulation at the mains may be somewhat more difficult, the single, combined service package greatly simplifies the installation of service lines to the buildings.

Electrical Tracing Layout

Figure 8 shows a schematic layout of the heat tracing circuits on a water distribution loop. Power is taken from a convenient source such as an above-ground power line (it could also be taken from a power cable buried along with the pipe). The power is fed to two double thermostats, each pair controlling adjacent circuits. The circuits are installed back-to-back so as to reduce the number of power point connections.

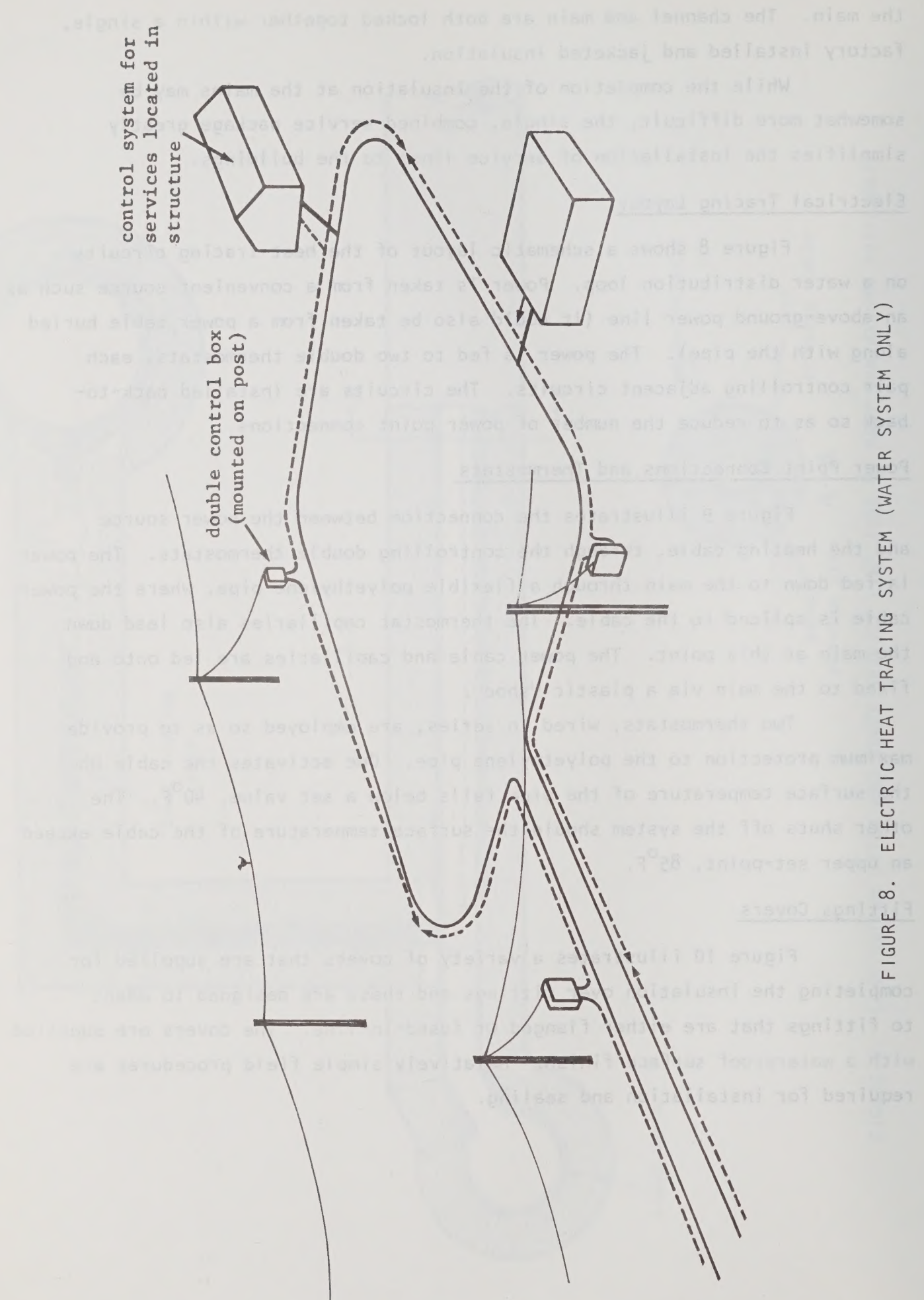
Power Point Connections and Thermostats

Figure 9 illustrates the connection between the power source and the heating cable, through the controlling double thermostats. The power is fed down to the main through a flexible polyethylene pipe, where the power cable is spliced to the cable. The thermostat capillaries also lead down the main at this point. The power cable and capillaries are led onto and fixed to the main via a plastic "shoe".

Two thermostats, wired in series, are employed so as to provide maximum protection to the polyethylene pipe. One activates the cable when the surface temperature of the pipe falls below a set value, 40°F. The other shuts off the system should the surface temperature of the cable exceed an upper set-point, 85°F.

Fittings Covers

Figure 10 illustrates a variety of covers that are supplied for completing the insulation over fittings and these are designed to adapt to fittings that are either flanged or fused-in-line. The covers are supplied with a waterproof surface finish. Relatively simple field procedures are required for installation and sealing.



each controller
contains high
and low limit
thermostat

controller
circuit A

controller
circuit B

capillaries

power supply to
cable

polyethylene
power point shoe

capillaries

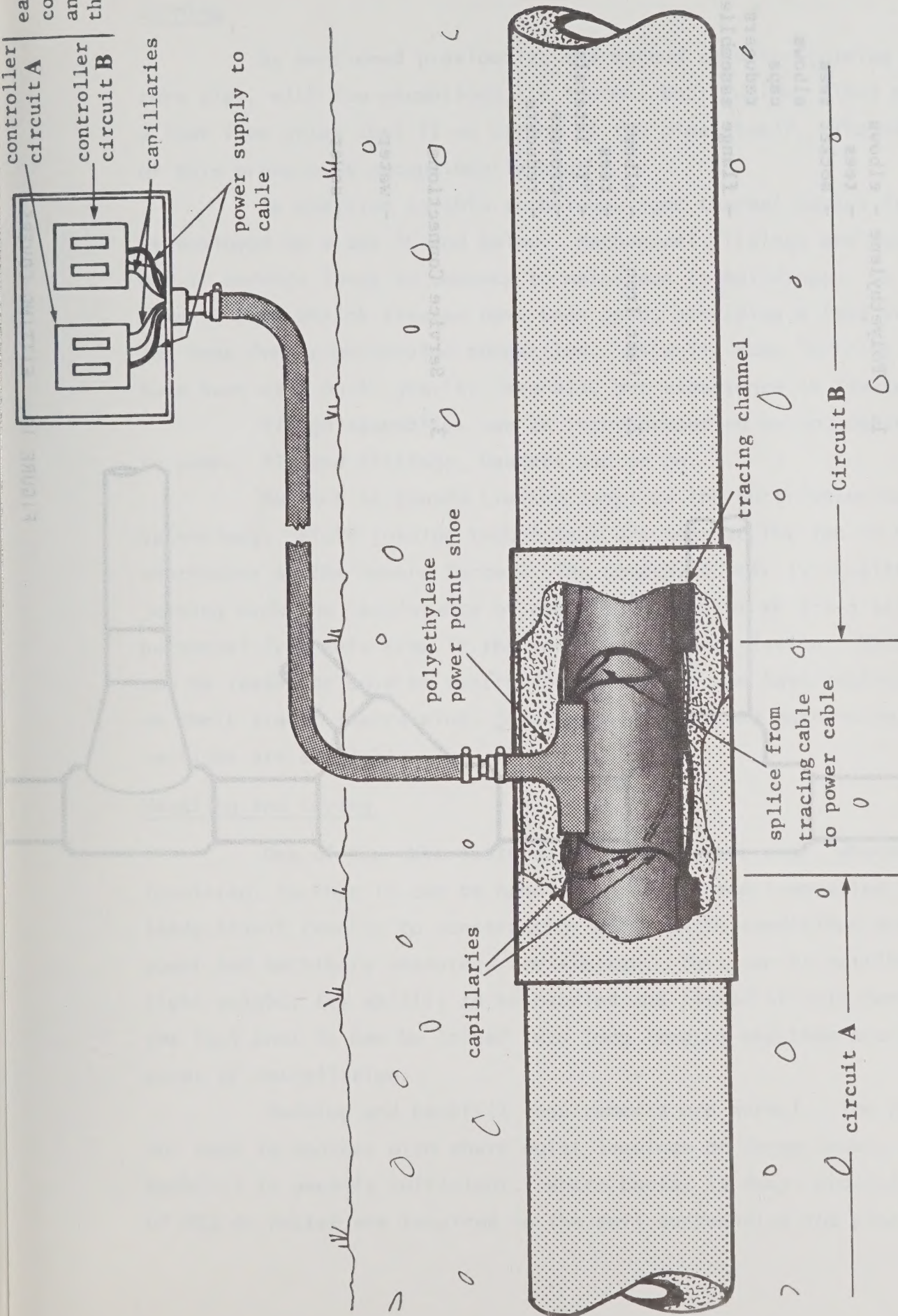
tracing channel

splice from
tracing cable
to power cable

circuit A

Circuit B

FIGURE 9. POWER POINT CONNECTION



Covers available for:

1. Polyethylene
 - elbows
 - tees
 - socket tees
 - elbows
 - caps
 - reducers
 - flange assemblies

2. Cast Iron
 - elbows
 - tees
 - "Y" laterals
 - crosses
 - reducers

3. Service Connections

- water
- sewer

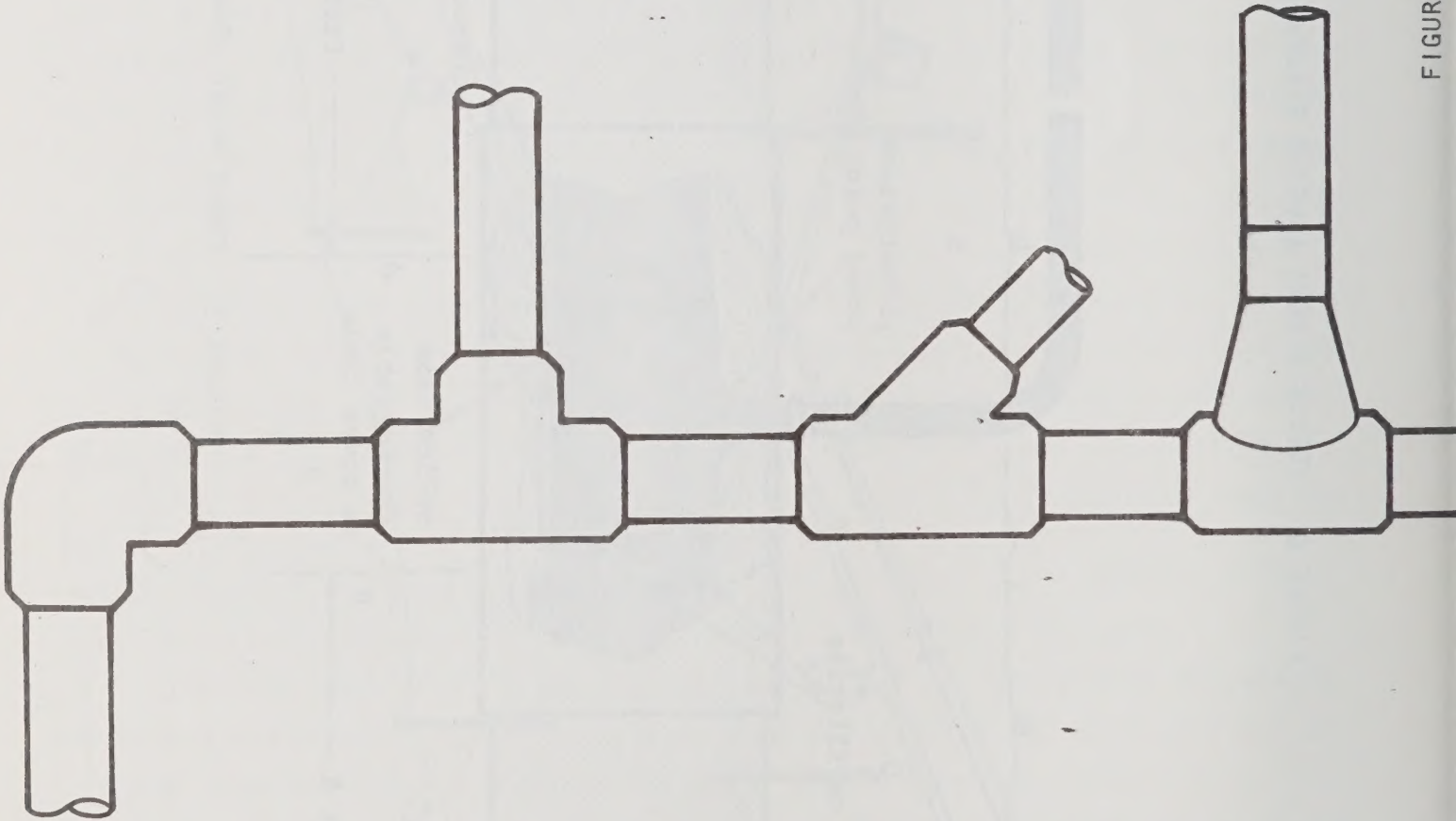


FIGURE 10. FITTING COVERS

INSTALLATION

Joining

As mentioned previously, the method used for joining the HDPE core pipe, with few exceptions, is thermal butt fusion. This produces a leak free joint that is as strong as the pipe itself. The reliability of this process is exceptionally high.

In addition to this technique, some thermal socket fusion is employed on sizes 4" and below. Mechanical fittings are used on 3/4" and 1" service lines to connect to mains and in buildings. On gravity sewers, heat shrink sleeves have been used, providing a fast inexpensive and leak free pipe-to-pipe connection. As well, some "O" ring couplers have been used on 4" gravity laterals, but experience is limited.

Flange assemblies can be incorporated so as to connect the pipe to pumps, flanged fittings, headers and so on.

Du Pont of Canada Limited supplies the butt-fusion machinery and technology. Field joining technicians are sent to the job to work with the contractor or the owners forces. The Company's role is to either do the joining with the assistance of the field crew, or to train selected personnel from this crew in the technique of butt fusion. Machinery can be leased or sold to contractors or owners who have trained people on their staff. Retraining, joining inspection and machine maintenance services are available.

Handling and Laying

One of the main features of polyethylene pipe, whether plain or insulated, is that it can be handled in unique and innovative ways. It lends itself readily to construction under harsh conditions and where manpower and machinery resources are limited. This can be attributed to its light weight, its ability to be handled and flexed at cold temperatures and the fact that it can be joined into long lengths and then brought to the point of installation.

Bedding and backfill requirements are normal. The pipe must not come in contact with sharp point loadings or large rocks. Selected backfill is usually sufficient. Where burial is deep, proctor densities of 85% or better are required in the soil surrounding the pipe.

Costs

It is beyond the scope of this paper to detail comparative costs. However, it can be stated in general terms that this system has inherent cost benefits, above and beyond its operational value, due to the high percentage of factory input. Where possible the requirements for on-site labour, particularly of a non-routine nature, have been reduced or eliminated. In addition, the single supplier concept has benefits in the areas of co-ordination, logistics, continuity and reliability.

OPERATION AND MAINTENANCE

A detailed review of the operational performance, particularly from an engineering standpoint, is also beyond the scope of this paper. It should be noted that others are studying and reporting on this matter.

Several case histories are worth reviewing as they illustrate many of the points raised so far. One concerns Rankin Inlet, N.W.T., where installation of insulated and heat traced "Sclairpipe" was started in 1973. During the first winter of operation a power outage occurred in the town. The recirculating system was down for approximately two days, although power was actually restored to the area, including the heat tracing lines, somewhat earlier. As a result, the older, above ground, hot water traced utilidor system froze and the pipes burst. A second and more recent buried utilidor system was successfully returned to operation. The insulated and traced "Sclairpipe" system, which had been temporarily installed above ground under very adverse conditions, was also successfully put back into operation. It was not determined whether or not this line froze. What is significant is the fact that this system, which had been designed for buried conditions, was fully operational once power was restored, notwithstanding the temporary and hasty nature of its installation. The installation of this system continues at Rankin with the next phase due this summer.

There are two cases known where "Sclairpipe" was frozen and then thawed out and returned to service without any damage to the pipe. One occurred at Baker Lake where the M.O.T. deliberately froze the insulated heat traced system as a test. The other concerned the accidental freezing of an uninsulated "Sclairpipe" line at Gillam. This line was steam thawed and returned to normal service.

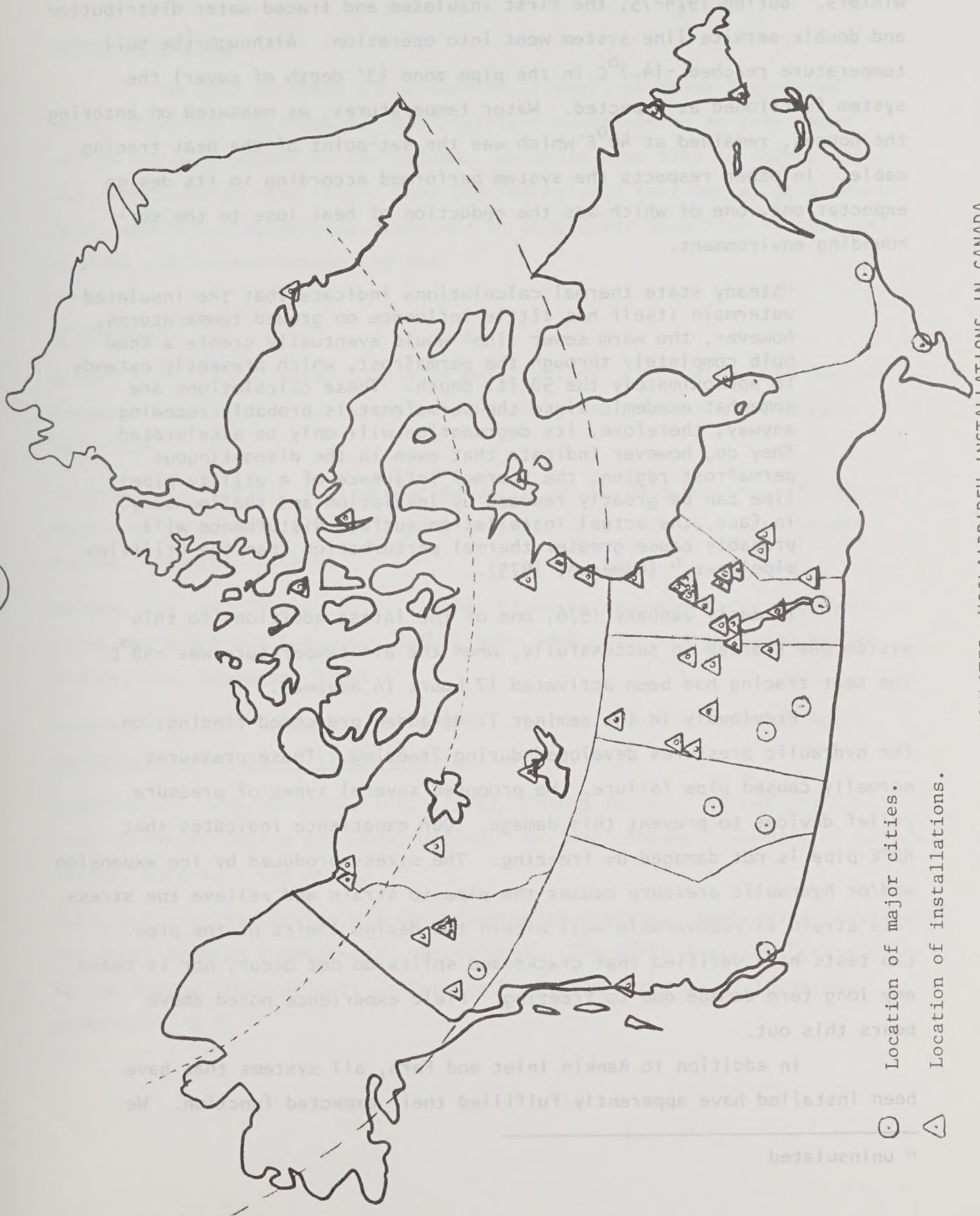


FIGURE 11. INSULATED "SCLAIRPIPE" INSTALLATIONS IN CANADA

Another case history is from Faro, Y.T. where a variety of insulated "Sclairpipe" lines have been in operation over the past two winters. During 1974-75, the first insulated and traced water distribution and double service line system went into operation. Although the soil temperature reached -14.7°C in the pipe zone (3' depth of cover) the system functioned as expected. Water temperatures, as measured on entering the houses, remained at 40°F which was the set-point of the heat tracing cable. In other respects the system performed according to its design expectations, one of which was the reduction of heat loss to the surrounding environment.

"Steady state thermal calculations indicate that the insulated watermain itself has little influence on ground temperatures, however, the warm sewer line* would eventually create a thaw bulb completely through the permafrost, which presently extends to approximately the 50 ft. depth. These calculations are somewhat academic since the permafrost is probably receding anyway, therefore, its degradation will only be accelerated. They do, however indicate that even in the discontinuous permafrost region, the thermal influence of a utility pipeline can be greatly reduced by insulation and shallow bury. In fact, the actual installation surface disturbance will probably cause greater thermal perturbation than the utilities pipelines." (Cameron, 1975).

In early January 1976, one of the latest additions to this system was started up successfully, when the air temperature was -48°C . The heat tracing had been activated 17 hours in advance.

Previously in the seminar T. McFadden presented findings on the hydraulic pressures developed during freezing. These pressures normally caused pipe failure. He proposed several types of pressure relief devices to prevent this damage. Our experience indicates that HDPE pipe is not damaged by freezing. The stress produced by ice expansion and/or hydraulic pressure causes the pipe to strain and relieve the stress. This strain is recoverable well within the design limits of the pipe. Lab tests have verified that cracks and splits do not occur, nor is there any long term damage due to freezing. Field experience noted above bears this out.

In addition to Rankin Inlet and Faro, all systems that have been installed have apparently fulfilled their expected function. We

* uninsulated

do not have any reports of systems failing to operate due to breakdown or shortcomings within themselves.

ACKNOWLEDGEMENTS

We wish to thank Bob Zimmerman, P.Eng., of Perma Engineered Sales, Winnipeg, Manitoba for his excellent contribution to this paper and to the development of the system. We would also like to acknowledge the assistance of many others from the Federal and Territorial governments, from consulting engineering firms and in particular Shaw Pipe Protection Limited and Thermon Canada Limited.

REFERENCES

- Alter, A.J. (1969), Water Supply in Cold Regions. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Monograph 111 - C5A.
- Cameron, J.J. (1975), Shallow Buried Utilities in Cold Regions. Preliminary Report on Faro, Y.T. Utility Expansion Study Site. E.P.S., Environment Canada, Edmonton, Alberta.
- Dawson, R.N. and Slupsky, J.W. (1968), Pipeline Research Water and Sewer Lines in Permafrost Regions. Report NWR. 68-8, Dept. of National Health and Welfare, Edmonton, Alberta.
- Gamble, D.J., and Lukomskyj, P. (1975), Utilidors in the Canadian North, Canadian Journal of Civil Engineering, Vol. 2, 1975.
- Lukomskyj, P. and Thornton, D.E. (1975), Piping system. Permafrost Engineering Manual-Design and Construction. National Research Council of Canada, Ottawa, Ontario. (in press)
- Ryan, W.L. (1973), Design and Construction of Practical Sanitation Facilities for Small Alaskan Communities. Permafrost: The North American Contribution to the Second International Conference. National Academy of Sciences, Washington, D.C.

APPENDIX I - DESIGN CRITERIA FOR WATER AND SEWER UTILITIES IN REMOTE,
COLD REGIONS

- Reduce heat loss, to conserve energy and to prevent heat leakage to the permafrost or soil.
- Prevent freezing, in the event of loss of flow.
- Prevent pipe breakage if frozen, to ensure a system can be returned to operation once it has been thawed out.
- Allow for simple thawing procedures, to reduce on-site maintenance and to put system back into operation as quickly as possible.
- Reduce energy requirements, to keep costs down and to limit load on the central equipment.
- Remain flexible at all temperatures, to prevent breakage during handling and during ground heaving.
- Have zero fluid leakage, to prevent damage to the environment or to the insulation.
- Be light weight, to reduce bearing weight on unstable soils and also to reduce cost of shipping (allow for air transport) and to simplify equipment and labour needs in handling.
- Be suitable for shallow burial, to facilitate low cost installation and to reduce overall damage to the environment via deep burial.
- Be easy and simple to install, allowing local unskilled labour to handle and join and to be "forgiving" in these circumstances, i.e., more tolerant of rough handling than most other pipe systems.
- Be easy and simple to operate, allowing local manpower to run and repair the system. Also, it must be tolerant of water hammer in the event of improper operation.
- Have long term reliability.
- Be low cost, in terms of purchase price, installation and operation.

APPENDIX 2(a) - CHARACTERISTICS OF "SCLAIRPIPE" HD POLYETHYLENE PIPE

- light weight
- flexibility
- good cold weather properties
- ductility
- non-corrodability
- low surface friction
- leak-free joining
- high insulation value
- electrical non-conductivity
- low water hammer

APPENDIX 2(b) - SHORT FORM "SCLAIRPIPE" SPECIFICATION

Raw material and pipe reference specification:

CGSB - 41-GP-25

BNQ - 3624-027

CSA - B 137.0 and B 137.1

ASTM - D-1248

ASTM - D-3035

Raw material designation (ASTM D-1248): High-Density Polyethylene P34.

Pipe Designation (CGSB 41-GP-25): PE 3507

Compounded Density (ASTM D 1505): 0.952 gm/cc

Pipe Size Range: 3/4" to 48" nominal

Pipe Series Range: 45 to 160 psi

APPENDIX 3 (a) - CHARACTERISTICS OF POLYURETHANE FOAM

- Low heat transfer
- Closed cell structure

- Relative flexibility
- Light weight
- High compressive strength
- High overall value
- Can be factory applied

APPENDIX 3(b) - COMPARATIVE INSULATION PROPERTIES

TYPE OF INSULATION	k FACTOR*	DENSITY lb/ft ³	APPLICATION	STRENGTH	EFFECT OF WATER
PU - Rigid foam	0.15	2.2	Factory applied to pipe.	35 psi Comp.	Medium
PS - Expanded	0.30	1.8-3.3	Preformed halves applied in field.	30 psi. Comp.	Little
Asbestos	1.08	12	" "	Low - brittle	Bad w/ freeze
Glass-foamed	0.50	9	" "	High - brittle	Little
Fibreglass	0.35	7	Wrapped over pipe.	Low	Bad w/ freeze

* BTU - in/hr - ft² - °F

PU - Polyurethane

PS - Polystyrene

APPENDIX 3(c) - SHORT FORM INSULATION SPECIFICATION

Insulation:

Material: Rigid polyurethane foam (supplied by Shaw Pipe Protection)

Density (ASTM D 1622): 2.2 to 3.5 lb/ft³

Closed cell content (ASTM D-2856): 90% minimum

Water absorption (ASTM D-2842): 12 gm/1000 cc

Thermal conductivity (ASTM D-2326-64T): 0.13 BTU-in/hr-ft²-°F at 77°F

Dimensional stability (ASTM D-2126 procedure B & E): 3%

Compressive strength (ASTM D-1621-64): 35 psi at 10% deflection

Jacket:

1. Material: - steel (galvanized, PVF painted, plastic coated, stainless)
- aluminum

Thickness: 16 to 30 ga (USSG)

Outside diameter range: 4 to 56 in.

2. Material: polyethylene

Thickness: 45 mil minimum

Tensile strength (ASTM D-1248): 3000 psi minimum

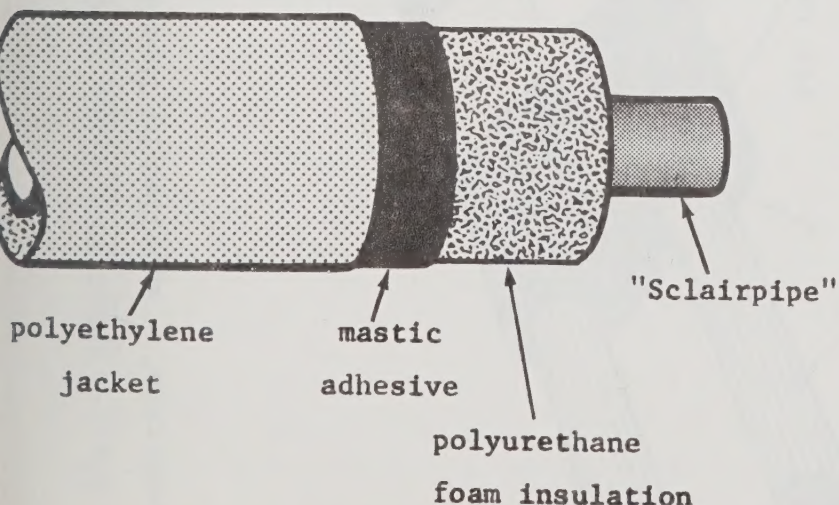
Hardness (shore D): 65

Outside diameter range: 4 7/8 to 18 1/2 in.

1.

Polyethylene jacketed insulation

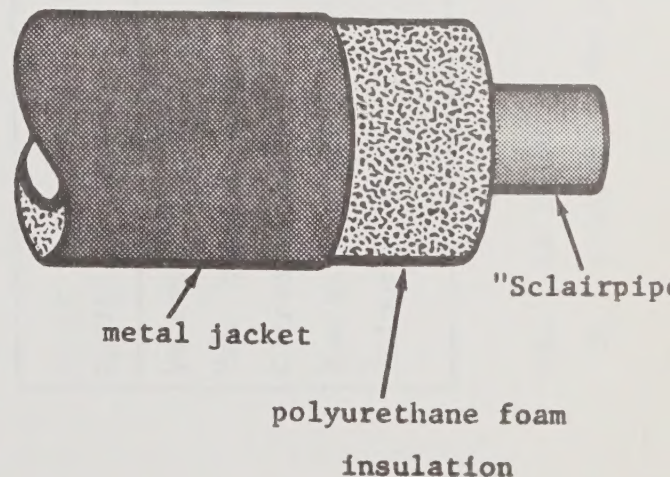
("Insul-8")



2.

Metal jacketed insulation

("Spiral-8")



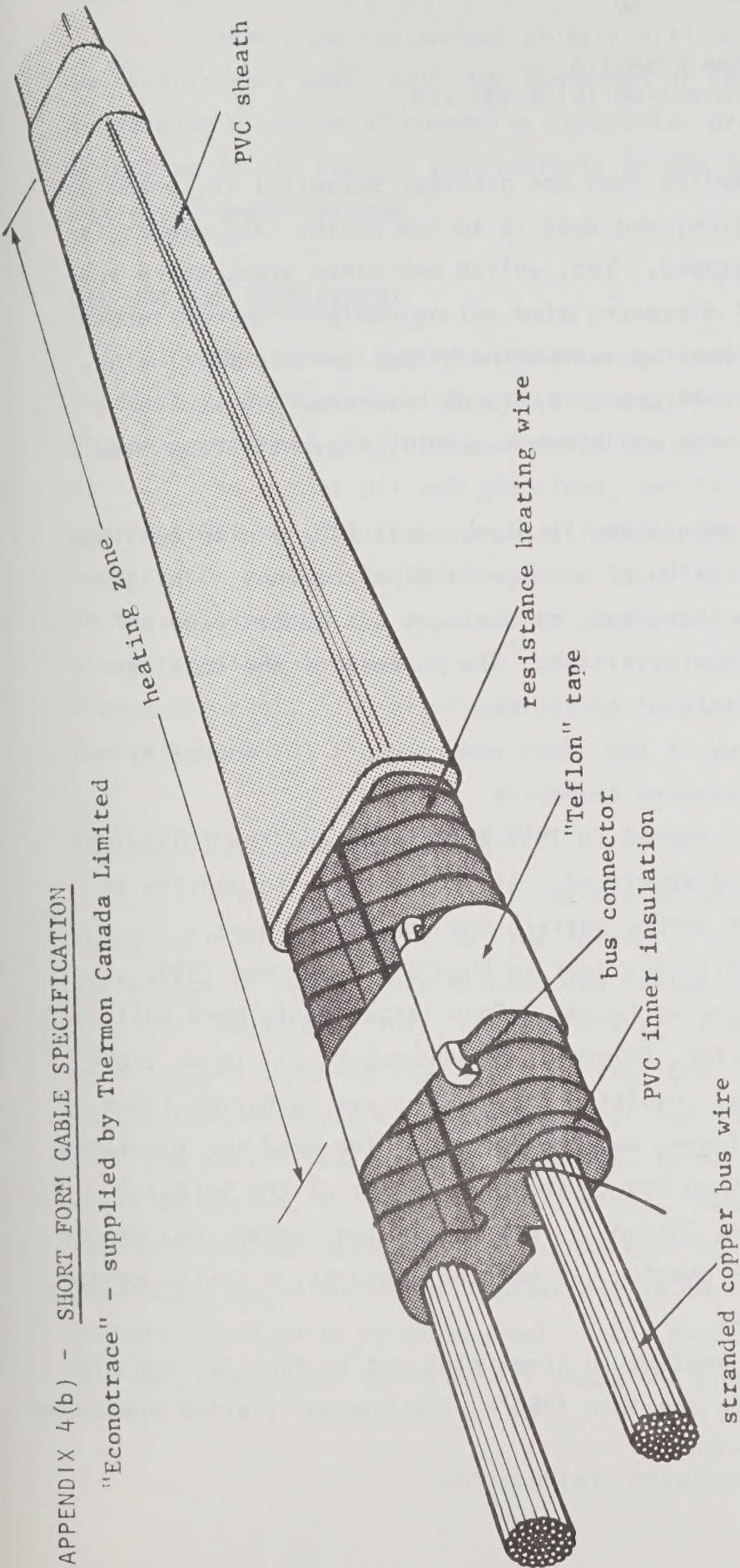
APPENDIX 4(a) - CHARACTERISTICS OF THE TRACING CABLE

The cable selected for this system is a parallel resistance type having a series of heating zones producing a constant watt/per foot output.

- Constant heat output.
- Can be cut to length.
- Long circuit lengths.
- No special voltage regulators.
- Flexible and rugged.
- Moisture resistant.
- Does not cause R.F.I.
- Simple to install
- Matched thermostat control.
- Compatible with HDPE pipe system.
- CSA approved and UL listed.

APPENDIX 4(b) - SHORT FORM CABLE SPECIFICATION

"Econotrace" - supplied by Thermon Canada Limited



CABLE DESIGNATION RATING (watts/ft)	A 4	B 8	C 4	D 2½	DD 2½
Voltage (watts)	115	115	230	115	115
Max. circuit length (ft)	500	250	700	400	100
Current (amps/ft)	0.034	0.069	0.017	0.021	0.021
Bus wire (AWG)	12	14	14	14	18
Colour	blue	red	yellow	black	black

CSA LR 24346

UL E-56615 Project No. 74CH 781

PIPE INSULATION AND PROTECTION*

by

Ron Franklin
Shaw Pipe Protection (Alberta) Ltd.

It is not hard to realize that the greatest potential in Canada's growth lies in one main direction, and that is to the north. The wealth is already there, waiting to be tapped. Yet, unlike any other area, there are several key demands: those of distance, also unimaginable in normal terms; those of terrain, some of the most varied on the globe; and, in particular, those of temperature, the most extreme to be found anywhere. To tackle the north and its inherent problem calls for ingenuity, inventiveness, and imagination.

The topic of this presentation is pipe, particularly pipe coatings. This involves the custom application of a range of pipe coatings, linings and insulation systems for the petroleum, natural gas and water resource industries as well as the various utilities. The purpose of the coatings is to protect pipe from every type of corrosion.

Since the 1930's, many of the ideas and concepts introduced by Shaw have become accepted as industry standards.

The first major plant opened in 1953 at Toronto and the following year a new Shot Blast Method was developed. Its purpose was to provide an improved and completely uniform anchor pattern for coating of pipe.

Perhaps the most significant year in Shaw's history was 1959, when Yellow Jacket was introduced to Canada. Four large plants were built in Western Canada at Regina, Edmonton, Calgary, and Vancouver, all in an eight year period. In 1965, a special insulated coating for use in buried lines known as Insul-8, and shrink sleeves were introduced. The need for insulated products for above ground use then led to the development of the Spiral-8 Process in 1971. Other products include: internal lining, epoxy, and cement mortar lining, coal tar asphalt coating, as well as Bondural, a fusion bonded, electrostatically sprayed epoxy.

Yellow Jacket can be applied to steel pipe and to ductile iron pipe for municipal installations. In the late 1960's, the company started producing

* This is an edited form of the taped presentation.

materials for the municipal insulation field and are now involved in townsite sewer and water design all over Northern Canada.

Shaw Pipe has worked closely with Du Pont, Thermon and, in the early discovery days, with Bob Zimmerman of Perma Engineering in Winnipeg to develop a number of composite insulation products. They have proven highly effective in the field; particularly in the insulation of pipe lines for water and sewer systems.

OIL AND GAS INVOLVEMENT

The demand for insulation on gathering systems requires our full capacity to produce Insul-8. At present, there are over 1400 miles of it underground on several continents, and not one case of failure has been reported.

In normal oil and gas lines, sufficient temperature is achieved by pre-heating, so that the medium arrives at the outlet with no further heating required on route. As the length of the line increases, the design engineer in the "oil patch" has to allow for intermediate re-heating, and that's not always possible because of the rough terrain, the immense distance, or the staggering cost. The alternative is to minimize any heat losses by the use of insulation.

WHAT ARE THE HEAT LOSS FACTORS?

There are three major factors which affect the heat balance. These are: the rate of flow, the thickness of the insulation, and the difference in temperature between the medium and the environment.

Because of this, we have worked closely with various designers on a systems approach that would control gas hydration. An early example was at the Lookout Butte Field on a project for Gulf's forerunner, B.A. Oil. Over the entire length of the pipeline, three additional line heaters would be needed, using uninsulated pipe. These would cost three hundred thousand dollars (\$300,000). So it's easy to see the "dollar and sense" advantages of polyurethane insulation, as more and more gathering systems are installed north of 60 degrees in the Mackenzie River Delta and at the many compressor stations all along the proposed line.

WHY SHOULD WE INSULATE PIPE AND FITTINGS?

The most common reasons are prevention of heat losses, prevention of changes in oil viscosity, to prevent hydrate formation, and in the municipal utility field as freeze protection.

Another area to consider is in refrigerant applications. There the emphasis is on prevention of heat gain. A final and extremely important reason in the whole nation's eye today is to prevent heat transfer either to the air or to the soil.

The material polyurethane was perhaps one of the few benefits to come out of the tragic war years. It was developed in 1937 by a German chemist, Otto Bayer, and was used in the wings of aircraft by the Luftwaffe. It is produced by polymerizing certain polyester resins with a poly-isocyanate. The result is a rapid, highly exothermic reaction. Rigid polyurethane foams are created when we introduce fluorocarbons (usually Freon) as an integral part of the foam structure. After the mixture is put into the forming mold the reaction is very fast. In ten to fifteen seconds it's a creamy foam. In twenty seconds to two minutes it's a gel. There is a 95 percent rise within 120 to 150 seconds, and in the same amount of time, it is track free, ready to handle. This rigid polyurethane insulation is designated by the Canadian Government Specification: 41-GP-16.

The thermal conductivity or K-factor, is the amount of heat in BTU's per hour that will flow through a slab of material, one foot square and one inch thick, when one face of the slab is one Fahrenheit degree hotter than the other.

It takes three times the thickness to insulate with foamglass compared to polyurethane. This is because closed cell rigid urethane foam has exceptional insulation qualities, a thermal efficiency second only to vacuum systems, and a heat loss factor approximately half that of most other commercial insulations available today. The advantages are evident and the proof has been in the performance of Insul-8. Here are the main advantages:

bond strength	- high
water vapour permeability and water absorption	- low
load bearing and compressive strength	- high

chemical and bacteria resistance	-	excellent
dimensional stability	-	tops

All the evidence pointed to polyurethane as the very best insulation available today. Today we insulate pipe from 3/4 inch up to 60 inches in diameter. When pipe is to be buried, Insul-8 foam is directly bonded to the cleaned surface, then covered with a Butyl rubber adhesive plus a continuous outer-sheath of high density polyethylene.

THE FABRICATION PROCESS

The order of pipe is received and stored in our yard. It is then moved to a heated building and preheated by gas impingers up to 100 degrees F. This gets rid of any ice, snow, oil or grime. Next, it proceeds to the cleaning area and is shot blast cleaned to remove rust and mill-scale. This process establishes an anchor pattern which will insure a strong bond of urethane to the steel.

Shaw's process uses a mold system. Here the pipe is centralized into position and the mixture of resin-isocyanate material injected. It is then allowed to cure in the mold for a brief period. A visual inspection is made to detect any possible voids or irregularities. Then a 10 mil minimum polymerized butyl rubber adhesive is directly applied to the urethane surface. It is applied as a water barrier in the event of any damage to the outer skin. This is followed by a continuously extruded high density polyethylene outer sheath. This, of course, is best known by its trade name Yellow Jacket.

The insulation is then cut back from each pipe bevel by a predetermined distance (usually 7 inches). This allows access for line-up clamps during the welding process. A mastic sealant is next applied to the exposed urethane surface at the location of the cutback to provide a permanent water-proof barrier. The pipe ends are finally capped with plastic bags for protection during shipment.

PALLETIZING, SHIPPING AND HANDLING

After tallying, the completed pipe sections are moved outside where they are stored on padded skids. Palletizing or normal truck load-

ing would follow before the pipe's eventual arrival at the pipeline right-of-way. This is a specialized procedure. We have palletized steel pipe for shipment to Inuvik, near the arctic coast, and also loose loaded it in a "pyramid" fashion for loads that were being hauled all the way by truck.

HANDLING IN THE FIELD

Normal stringing operations using end hooks are employed. If some damage does occur to the outer sheath, it can be easily repaired by installing shrink sleeves. Field bending can be carried out in the normal manner, ensuring that padded bending shoes are used. The pipe is lowered-in, using cradles or slings. On pipe diameters greater than 12 inches, slings are usually recommended.

THE JOINING PROCEDURE

After welding and testing, the installation of "joint insulation" takes place. Shaw provides preformed halves of urethane which are taped in place. The joint is completed by shrinking down a Canusa heat shrink sleeve over the insulation. This is a fast and simple procedure which is done by one man with a propane torch. The Canusa "heat shrink" sleeve is a cross-linked polyethylene type expanded and internally coated with an adhesive. The application of heat activates a plastic memory and this causes the sleeve to shrink uniformly around the insulation. Due to the cross-linking of the polyethylene, the sleeve will not stress crack. Therefore, a field joint protected by a Canusa sleeve compliments the coating. The end result is a system that is impervious to moisture and chemical attack.

ABOVE GROUND INSTALLATIONS

Although Insul-8 is recommended for buried pipeline application, in certain instances it has been used above ground. In these cases, a "Black Polyethylene Jacket" is used to protect the external surface from ultra-violet degradation. However, for normal above ground applications, Shaw recommends our patented Spiral-8 process. As it is extremely versatile in application and manufacture, it will satisfy a wide range of thermal requirements to exacting specifications. This includes freeze protection for arctic gathering systems

and service lines, to preventing heat loss in hot oil lines. On-site labour costs are greatly reduced by matching insulated fittings of all types, which enable the "complete packaging" of Spiral-8 installations from inlet to outlet. Spiral-8 can be applied to straight pipe lengths in 1 inch to 60 inch size and on orders from a few feet to many miles.

HOW SPIRAL-8 IS MANUFACTURED

Just as in the Insul-8 process, the pipe is pre-heated and shot blast cleaned. At the manufacturing area, it is mounted on off-set wheels which rotate the pipe past the insulation station. The foam is then injected by the froth method, very similar to shaving cream. It is void free urethane foam of specific composition to provide exact densities and compressive strengths. At the same time a continuous lock seam of four ply steel is formed, and jointed in a spiral pattern. This "waterproof" seam forms a continuous seal and a vapor barrier of exceptional mechanical strength. The metal jacket may be of galvanized steel, aluminum, or epoxy coated steel in a number of colors. The normal thickness of jacketing is 22 AWG, which provides sufficient mechanical protection.

With each shipment of Spiral-8, pre-molded urethane half shells are provided to use on welded joints and fittings. When they are fitted in the field, along with a mastic water stop and also a metal outer cover, the result is a seal completely impervious to water.

Probably one of the biggest benefits of Spiral-8 is the fact that the entire operation can be performed by a relatively inexperienced crew, without specialized equipment. All of the handling, hauling and stringing procedures do not differ to any degree from normal pipelining. In the far north, with its distances and demands, this is a vital factor.

EXPANSION JOINTS FOR LOW-TEMPERATURE ABOVE GROUND WATER PIPING SYSTEMS

by

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University of Alberta
Edmonton, Alberta

INTRODUCTION

The development of systems to deliver water services for small communities presents some unique problems in permafrost regions. These problems have manifested themselves as system failures and have been a factor in the high costs of supplying such services in these communities. This paper will examine one of these problems and that is the problem of thermal compensation in the water system.

In underground water distribution systems relatively little compensation for expansion and contraction is needed since the pipes are buried at a depth at which the ground temperature variations are small. In permafrost regions, however, water piping systems are often installed above ground. These may be permanent water distribution systems as in a utilidor system [1], or merely water pipelines which are operational only during the summer months. In either case the piping must be designed to allow for expansion and contraction commensurate with the full range of air temperatures. This range may be as large as 160°F which for steel pipe translates into a length change of $1\text{-}1/4"$ per 100' of pipe. In the case of a water distribution system in which water at approximately 40°F is constantly circulated, the pipe would not normally experience the full range of air temperatures; however, these systems must on occasion be shut-down and drained for the purposes of maintenance or modification.

The three common techniques available for thermal compensation are:

- (1) a "snaked" or "zig-zag" line;
- (2) expansion loops with or without ball joints; and
- (3) an "in-line" expansion joint.

Each has specific advantages and limitations.

The "snaked" or "zig-zag" line (Figure 1) has perhaps some advantages as far as simplicity is concerned. It does, however, require more lateral space than the "in-line" expansion joint. For example with anchor points at 100' intervals a "snaked" line would have to be offset some 3' from a straight line. This means that the "snaked line" cannot be used in a utilidor although it may be acceptable when laying pipe over an open area. Less lateral offset is required if the anchor points are more closely spaced. For example with anchor points every 30' the offset is only half a foot. The radius of curvature of the pipe bends between anchor points, however, is too small for the large diameter pipes.

Expansion loops may be built into the line, however these tend to be expensive to install as well as substantially increasing the pressure drop in the line [2, 3, 4]. In some cases a rather simple expansion loop constructed with ball and socket joints has been tried. These joints have, however, failed under low temperature conditions.

The most feasible type of expansion compensator for a utilidor would be an "in-line" type of expansion joint. The normal procedure of designing for expansion and contraction using this type of joint is given in Reference [5]. Some types of "in-line" expansion joints are:

- (1) "dresser" type coupling;
- (2) packed slip type;
- (3) internally supported bellows; and,
- (4) free flexing bellows.

Sketches of these joints are shown in Figures 2 through 5.

The "Dresser" type coupling is not designed as an expansion joint; however, it will take about 1/4" of movement under normal conditions. Thus if they are spaced at 20' intervals they normally will suffice as expansion compensators in water piping.

The packed slip type is a much more sophisticated expansion compensator designed primarily for industrial plant use. A single unit can accommodate the large expansions, up to 12", that occur in high temperature lines.

The internally supported bellows and the free flexing bellows both employ a corrugated metal bellows to compensate for the expansion.

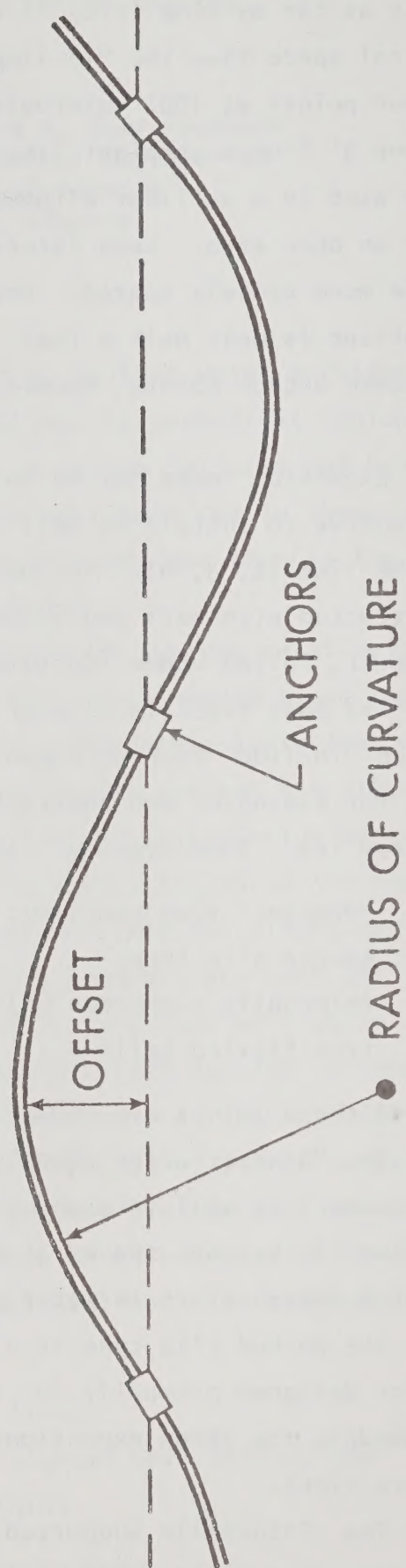


FIGURE 1. "SNAKED" LINE

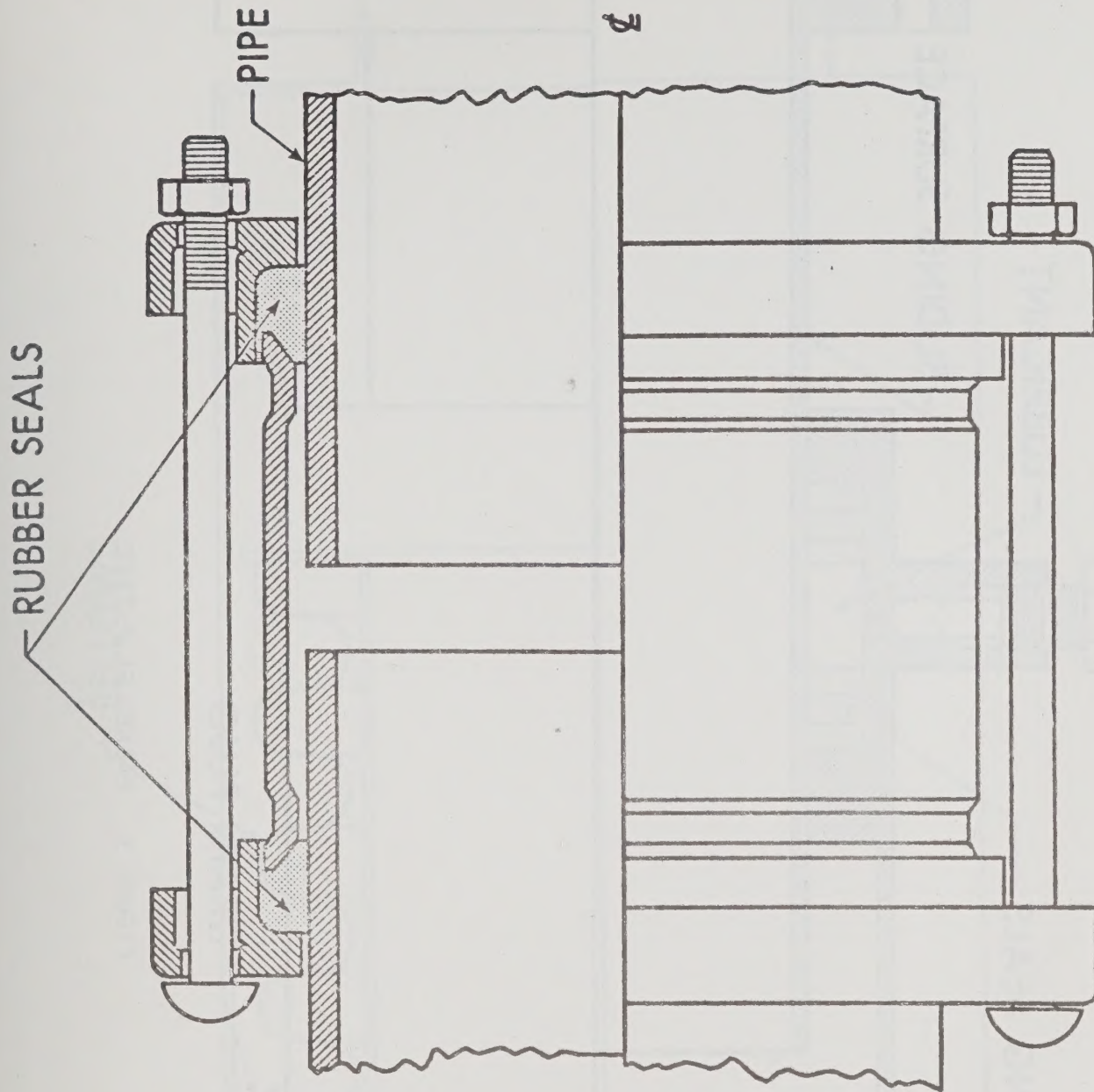


FIGURE 2. DRESSER COUPLING

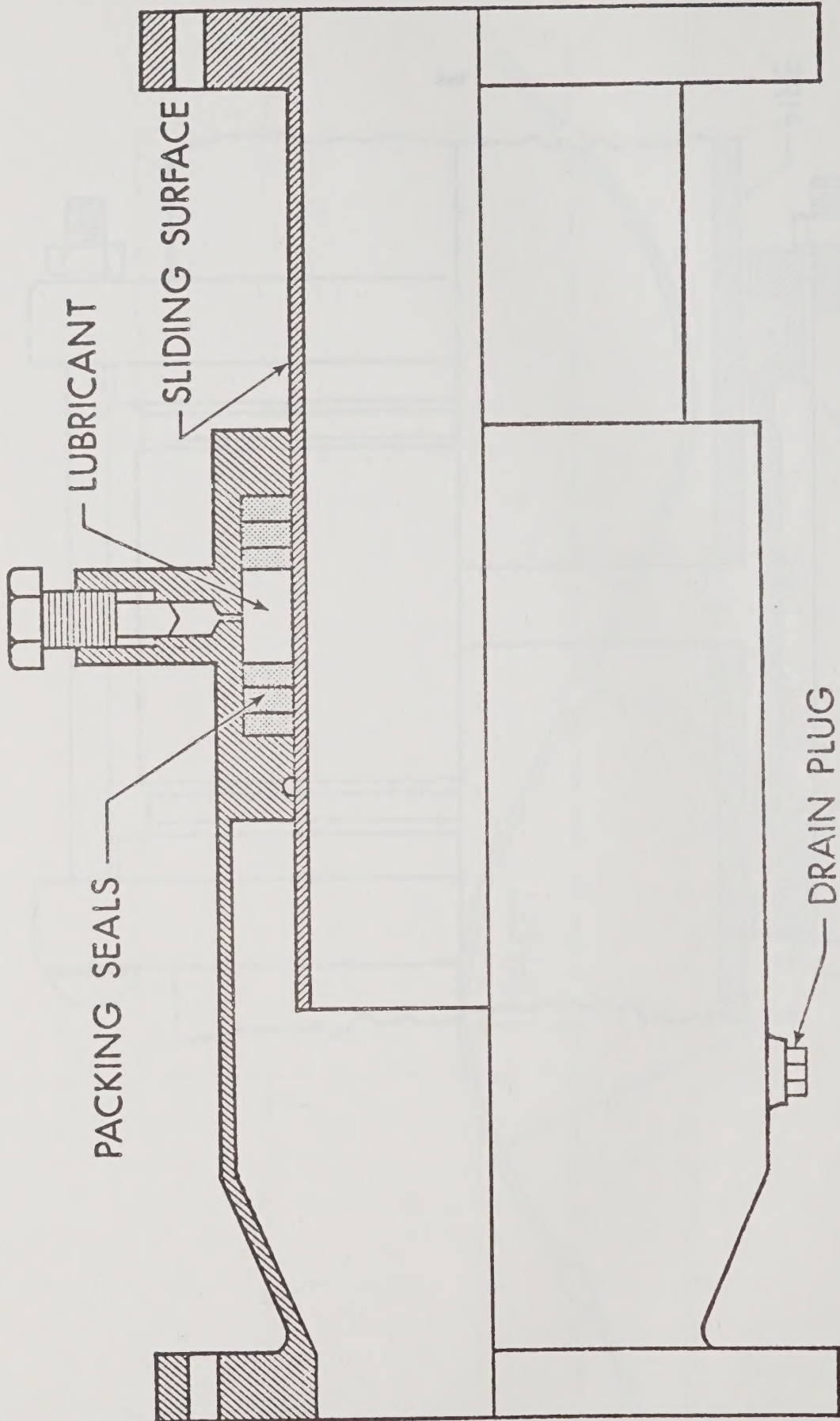


FIGURE 3. PACKED SLIP TYPE

BELLOWS

PIPE

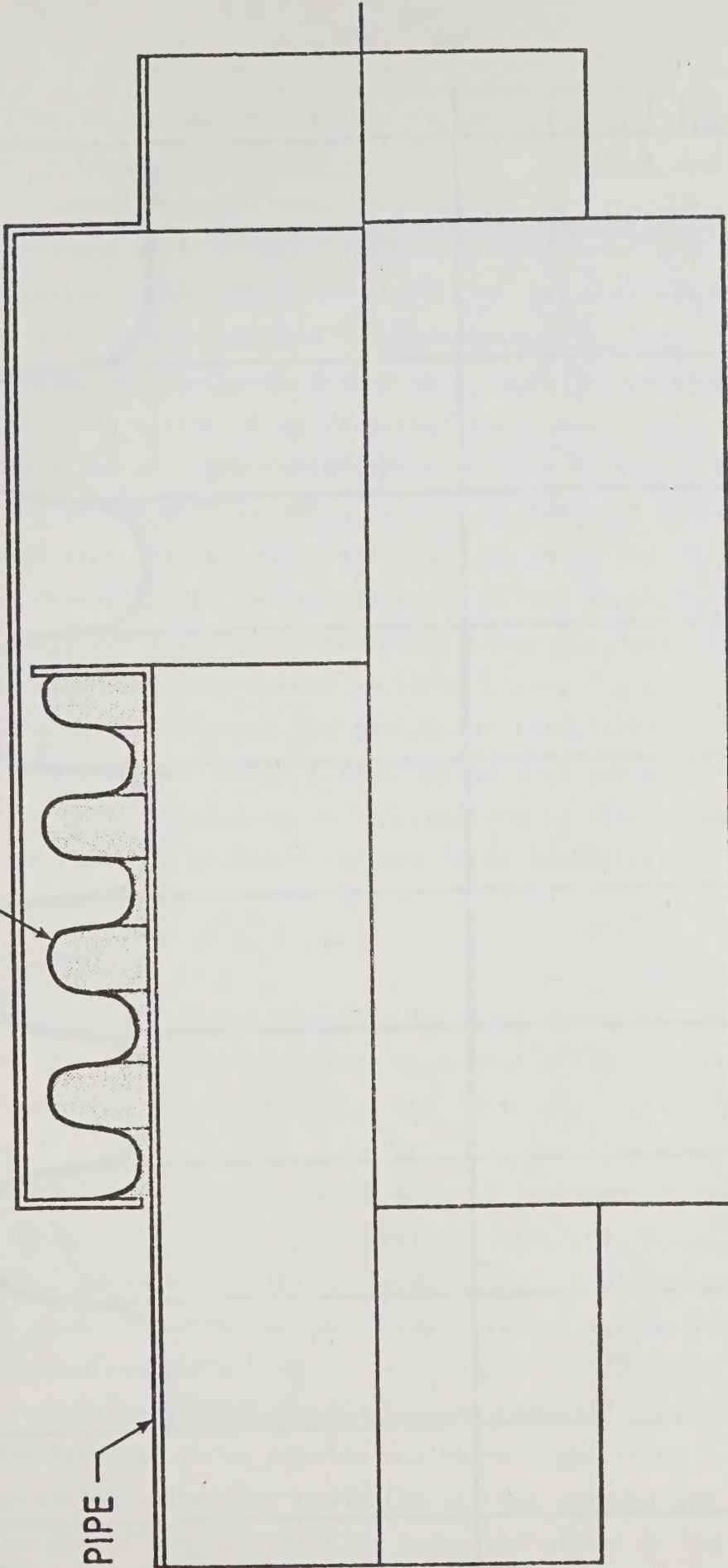


FIGURE 4. INTERNALLY SUPPORTED BELLOWS

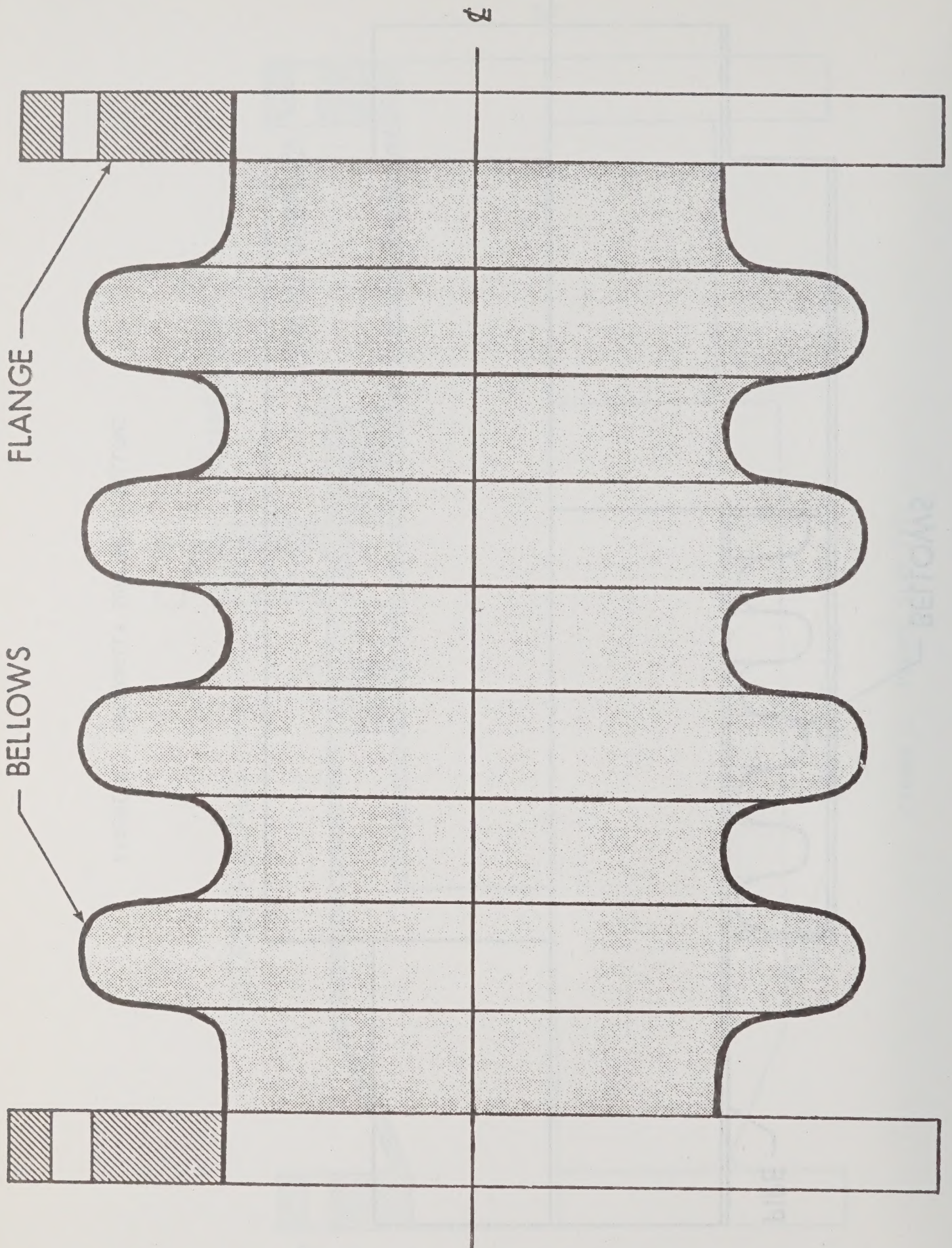


FIGURE 5. FREE FLEXING BELLOWS

They differ in the way the bellows is physically arranged in the joint as shown in Figures 4 and 5.

Operation experience compiled by the Canadian Department of the Environment with in-line type expansion joints in above groundwater piping systems in the north has shown that failures frequently occur if the pipe must be shutdown and drained during the winter. Failures have been observed to occur with a type of internally supported bellows joint and with piping system using "Dresser" type couplings. From these observations it was surmized that the reason the expansion joints were failing was that either the joints were becoming stiffer at the cold temperatures or that ice formed from the residual water left in the joint after the pipe was drained preventing the normal operation of the expansion joint.

It was therefore proposed to study the behaviour of a number of types of expansion joints used in steel piping systems under low temperature (sub-freezing) conditions. In particular their ability to expand and contract both with and without water frozen inside them was to be investigated by simulating these conditions in the laboratory. The primary objective was to find expansion joints which will perform satisfactorily in northern climates.

TEST PROCEDURE

Four different types of "in-line" expansion joints were tested. These are the "Dresser" coupling, packed-slip type, internally supported bellows and free flexing bellows. The particular joints tested are listed in Table 1.

In order to test the effects of low temperature and residual water frozen in the joint, the joints indicated in 1, 2, 3 and 4(b) of Table 1 were subjected to six different tests each. In all these tests the joints were expanded or contracted in a hydraulic testing machine. Figure 6 shows the configuration used for all tests. (The Dresser coupling inside the environmental chamber is shown as an example.) The six tests on each joint consisted of three tension and three compression tests. These tension and compression tests were conducted at room temperature (70°F) to give a basis for comparison, at -20°F to gauge the effect of low temperatures and at -20°F with water frozen inside the joint. In this last test with the

TABLE 1

TYPE OF JOINT

1. Dresser Coupling, Style 38, Item Code 0013, for 2" nominal pipe
2. "Slip-Pakt" expansion joint 150# flanged 2" nominal pipe; 4" traverse
3. Internally supported bellows Flexonic model H; 2" nominal pipe
4. Free-flexing expansion joint 3" nominal pipe: 150# flanges
 - (a) one with 4 corrugations
Flexonic model SFSF 0304
 - (b) one with 6 corrugations
Flexonic model SFSF 0306
 - (c) one with 8 corrugations
Flexonic model SFSF 0308

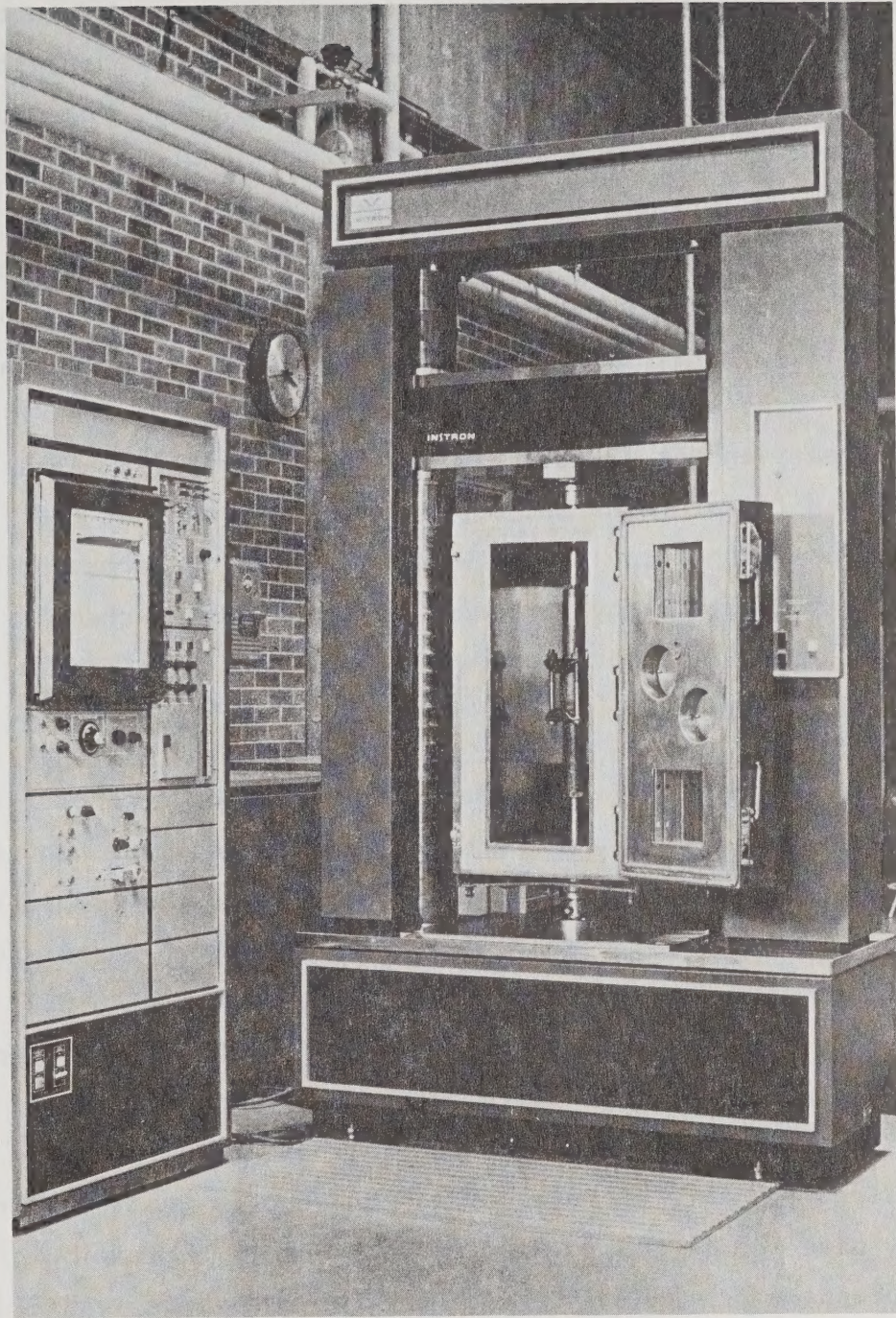


FIGURE 6. A COUPLING INSTALLED IN TEST APPARATUS
AND READY FOR TESTING

joint and connecting pipes in the horizontal position, water was put into the joint until it began running out of the ends of the pipe. The water was then frozen and the entire assembly transferred to the environmental chamber in the testing machine, cooled to -20°F and tested in tension. After the tension test the ice was melted and refrozen before commencing the compression test.

A further sequence of tests were conducted to determine the effects of larger amount of ice in the joints, as well as greater movements of each joint. These tests were concentrated on the packed slip and free flexing type of joint since the first series of tests had shown them to be superior.

As well a series of tests were done on free flexing joints of different lengths (number 4(a) and 4(c) Table 1). These tests were designed to determine the maximum compression that the free flexing joints with ice in them could take without suffering permanent deformations. To determine whether any permanent deformation occurred a visual check was made to see whether or not there was any distortion of the bellows.

RESULTS

The results for the first series of tests are summarized in Table 2. For comparison, the loads required for a 0.25 inch compression or expansion of the joint are shown. This corresponds to the compensation required per 100 ft of steel pipe after approximately a 30°F temperature rise. In some instances the load reached a maximum value before a 0.25 inch displacement was obtained and then the load fell off with further displacement. In these cases the maximum load is recorded.

Of particular interest in these results is the change in the force required to operate these joints that occurs when they are cold and when they have ice in them. Also of interest is the maximum force required for compression of the joint. For the two and three inch diameter joints tested it is estimated that the pipe between supports spaced 20 feet apart would buckle if the force in the pipe exceeds three or four thousand pounds. This would happen instead of the joint compressing.

The force required to operate the "Dresser" coupling which was high at room temperatures increased to 5000 or 6000 pounds when the

TABLE 2. FORCES REQUIRED TO OPERATE VARIOUS EXPANSION JOINTS UNDER NORMAL AND FREEZING CONDITIONS

	Tension (lb)			Compression (lb)	
	Room Temp.	-20°F	-20°F with Ice	Room Temp.	-20°F with Ice
1. Dresser Coupling (2" nominal pipe Style 38)	2100*	5000*	6350*	3700**	9700**
2. Packed slip type (2" nominal pipe Flexonic slip-Pakt)	400*	900*	600*	500*	2700*
3. Free flexing bellows (Flexonic 3" nominal pipe, Model SFSF 0306)	125**	125**	125**	125**	250**
4. Internally supported bellows (Flexonic 2" nominal pipe, Model H)	100**	100**	2400**	70**	3600*

*maximum force occurred before a displacement of 0.25" was reached

**force required for a displacement of 0.25"

joint was cooled to -20°F without any ice in it. The force increased even further when ice was frozen in it. It is, therefore, probable that such a joint would provide no expansion compensation under freezing conditions.

The internally supported bellows, which required forces of about 100 pounds at room temperature and at -20°F , required forces of the order of 3000 pounds when ice was frozen in them. These high forces were due to the design of the bellows structure (Figure 4) which traps the ice formed. It is surmized that this is the reason that internally supported bellows joints which have been tried in practice have failed during a shut-down cycle.

The forces required to operate the two remaining joints, the packed-slip type and the free flexing bellows, were acceptable under all conditions. However, the free flexing bellows showed the least adverse effect of having ice frozen in it.

If the amount of ice frozen in the joint was increased the force required increased considerably. For example, for the packed-slip type half full of ice the force required was 5000 pounds, whereas with the minimum amount of ice in it the force was 2700 pounds. One could conclude that any piping system must be designed so that the expansion joints will drain to the greatest extent possible. It should be pointed out that the slip type joint has provision for draining so that, properly installed and used, there should be little water left in this joint.

In tests where the amount of compression was increased from 0.25 inches to one inch it was found that the maximum force required for the packed-slip type was 3400 pounds while that for the free flexing bellows was 1000 pounds. (The specified maximum expansion for these joints are 4" and 1-1/2, respectively.) The higher force required for the packed slip joints, along with the fact that the maximum force is required near the beginning of their compensation under freezing conditions, limits their value. This leaves the free flexing bellows as the most acceptable expansion joint from a technical point of view.

The free flexing bellows were observed to suffer permanent deformation if they were compressed excessively with ice trapped in the bellows. Figure 7 shows the result of compressing the six corrugation

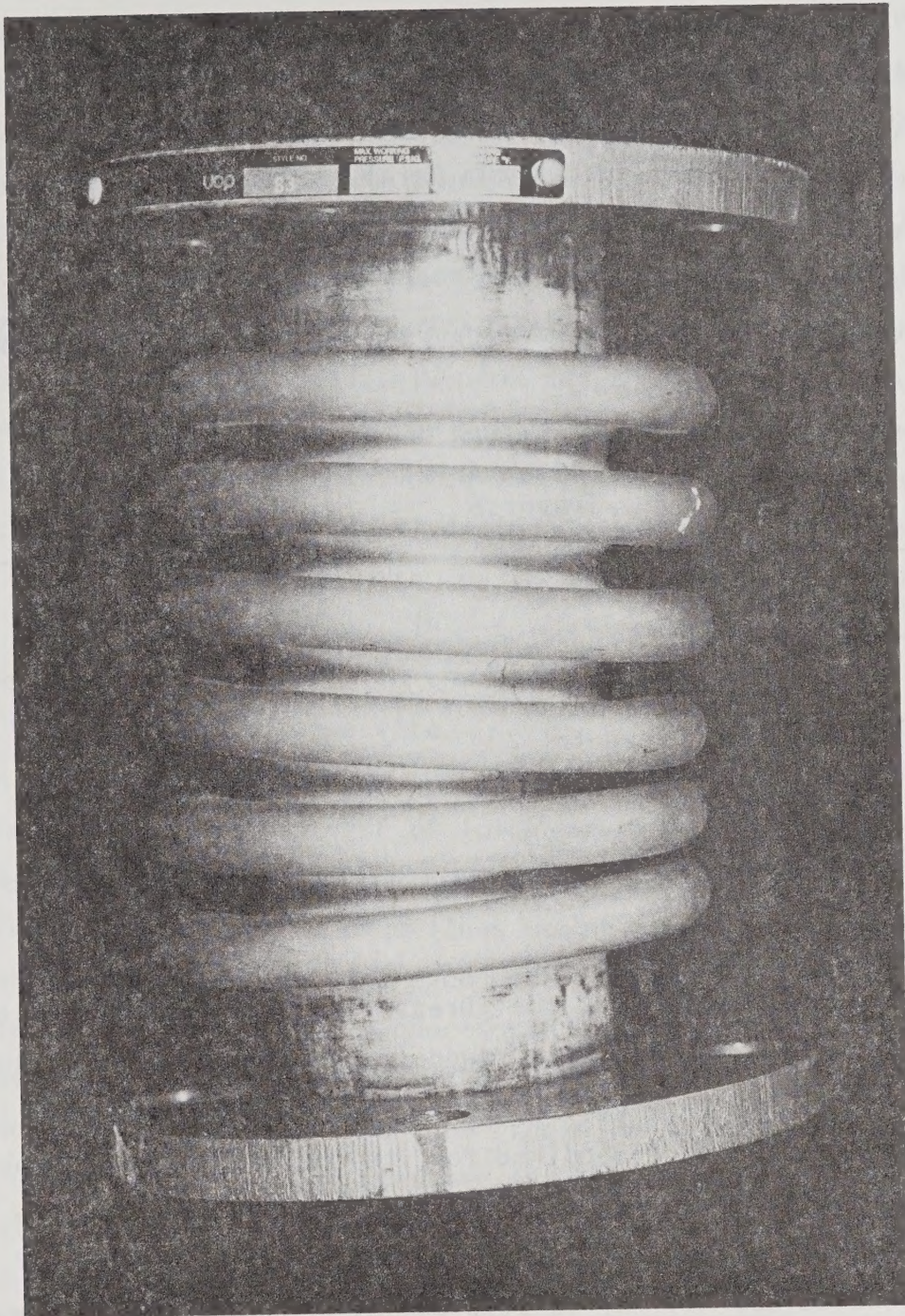


FIGURE 7. PERMANENT DEFORMATION DUE TO OVER COMPRESSION
OF A FREE FLEXING BELLOWS JOINT

free flexing bellows joint one inch. (The maximum traverse specified by the manufacturer is 1-1/2".) While permanent deformation has occurred the joint may still be able to perform its function in an adequate manner. Several sizes of joints were tested to determine the maximum compression that could be tolerated without permanent deformation. These results, along with the specified maximum axial traverse, are shown in Table 3. It will be observed that the maximum safe traverse with ice frozen in the bellows is above 50% of the normally specified traverse.

TABLE 3. MAXIMUM JOINTS TRAVERSE OF FREE FLEXING BELLOWS

	Specified Maximum Axial Traverse	Maximum Safe Traverse with Ice Frozen in Bellows	% of Specified Traverse
Flexonic SFSF 0304	1"	1/2"	50
Flexonic SFSF 0306	1-1/2"	3/4"	50
Flexonic SFSF 0308	2"	1"	50

CONCLUSIONS AND SUMMARY

The slip-packed, the 'Dresser' coupling, and the internally supported bellows joints were found to be unacceptable for low temperature application. The slip-packed type of joint functioned with ice frozen in it; however, the force required for its operation was increased by a factor of five. This along with the fact that these joints require large loads near the start of compression would make them unsuitable for the applications considered. It may be possible by means of design changes in this type of joint to reduce these loads considerably. Simply installing the joints in a non-horizontal position should reduce the amount of trapped water and should lower the loads required for movement. The other slip-type joint tested was the 'Dresser' coupling which is not specifically designed as an expansion compensator but allows approximately one-quarter inch per joint under normal conditions. It was found that this joint became

excessively stiff at low temperatures and would probably provide no expansion compensation under these conditions. The final type of joint tested was an internally supported bellows joint. In this joint, ice formed from residual water tended to be trapped and prevented normal operation. This type of joint, while relatively inexpensive, proved to be totally unacceptable under these conditions.

The only type of 'in-line' expansion joint that performed adequately was the free-flexing bellows joint. Low temperature conditions alone do not affect its operation. With residual water frozen inside, the bellows joint performed adequately provided the amount of contraction was limited to 50% or less of the specified amount for each joint. For contractions in excess of this value some permanent deformation may occur even though the joint may still perform adequately. The force required to compress the bellows with ice in them was a factor of two higher than the value without ice. This force was not excessive; however, it would have to be accounted for in the calculation of anchor forces [5] by doubling the specified bellows rate.

In designing supports for the free-flexing bellows joint it should be remembered that this type of joint can take quite a bit of angular misalignment; however, lateral misalignment of the pipe ends will cause problems. For a pipe supported on pilings where some shifting may occur, the joints should be laterally stiffened with alignment guides. Also, large amounts of shifting of the supports can be accommodated if a bellows joint is installed at each support so that each joint acts as a hinge.

Quotes on a number of sizes of free-flexing bellows joints were obtained in December of 1973. From these and the allowable expansion for each (one half of the specified value) the approximate cost per foot and the required expansion joint spacing shown in Table 4 were calculated. Note that the cost per foot of pipe is only the cost of the bellows joints and does not include the cost of pipe anchors, pipe guides, and associated installation costs. The prices are, of course, out of date now; however, they do indicate the trends involved. In each case the most economical joints to use are the ones with the most displacement per joint. The minimum cost for both the 3" and 6" pipe sizes, using ten corrugations per joint, was at that time around \$2.00 per foot of pipe. Factors such as ease of installation and the problem of maintaining alignment

of long sections of pipe may, however, override the use of the minimum cost joints. Since the cost of installation and repair of piping systems in northern communities is very high, the cost of the expansion joints may not be a major consideration.

This study has concentrated on one problem encountered in water services in permafrost regions, that is thermal compensation. There are many other potential causes of failure of such systems. These include the freezing of pipes and the movement of pipe supports due to frost action to name just two. It is believed, however, that by a systematic study of each possible cause of failure the reliability of water services in northern communities can be improved.

TABLE 4. EXPANSION JOINT COSTS

	Number of Corrugations Per Joint	Allowable Traverse (inch)	Required Joint Spacing (ft)	Cost of Bellows Joints Per Foot of Pipe
3" nominal pipe	4	0.5	40	\$3.60/ft
	6	0.75	60	2.65/ft
	8	1.0	80	2.19/ft
	10	1.25	100	1.90/ft
6" nominal pipe	6	1.12	90	2.75/ft
	8	1.5	120	2.25/ft
	10	1.88	150	1.96/ft

ACKNOWLEDGEMENTS

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REFERENCES

1. R.J.E. Brown, Permafrost in Canada, Chapter 5, University of Toronto Press, 1970, 82-104.
2. E.W. Bramley, "Tables Provide Short Cut for Pipe Stress Analysis", Heating, Piping and Air Conditioning, 36, March 1964, 104-107.
3. E.W. Bramley, "Avoid Overstressed Piping Through Flexible Layout", Heating, Piping and Air Conditioning, 36, April 1964, 125-127.
4. A.W. Heath, "An Economic Comparison - Expansion Joints vs Pipe Loops", Heating, Piping and Air Conditioning, 27, October 1965, 101-104.
5. R.H. Good, "The Use of Bellows Expansion Joints", Pipe and Pipelines International, April 1971, 28-34.

THE VACUUM SEWAGE SYSTEM

by

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INTRODUCTION

Although there are less than one hundred thousand people living north of Canada's 60th parallel, it is likely that billions of dollars will be spent over the next decade to locate, collect, and transport a portion of the natural resources in this area.

Man and machine have already started moving into this hostile environment.

A major problem is providing twentieth century comfort to the work force while maintaining an unchanged northern environment, with due consideration to the economic development.

As a result of the development of our civilization, the majority of utilities and services - which we now consider a natural part of our daily life - has been mechanized, especially in these northern regions.

In most cases, we have changed from systems that are dependent upon natural forces or phenomena, to systems which rely on generated energy. Thus we no longer light or heat by means of open fire nor do we rely entirely on gravity for the supply of water and transportation of sewage.

The mechanization of utilities, which for the greater part has taken place over the last 100 years, has been spurred mainly by the rapid growth of our cities. This mechanization has not only increased individual comfort but has also made these services a way of life at an economical level, even though they may not always allow rational use of our natural resources. The only notable exception is the transportation and treatment of household wastewater, which, in most communities remains the only unmechanized service. The transportation of sewage in most of these communities relies partly or totally upon gravity. Treatment, to a large degree also relies upon natural phenomena. As a result, the existing conventional sewage system is to a certain extent inefficient, oversized and wasteful of one of our most important natural resources, clean unpolluted water.

THE SYSTEM

The vacuum sewage system is designed for the transport of industrial and household wastewater. The system was invented and patented in the early 50's by a Swedish engineer, Mr. Joel Liljendahl. In 1969 AB Electrolux, Stockholm acquired the worldwide rights for the system. Vacusan Systems Limited is the Canadian licensee for Electrolux's Environmental Systems Division.

The main objectives of the inventor were:

- a.) to save water;
- b.) to minimize treatment cost and control pollution; and,
- c.) to transport sewage independent of grade in small diameter pipes.

The first objective, to save water, is achieved by utilizing a special vacuum toilet, which uses only $\frac{1}{4}$ gallon per flush as compared to 4 to 5 gallons for a conventional toilet.

The second objective, is partly achieved in that the less water used the less that has to be treated. By using vacuum toilets and high pressure shower heads the water consumption in a workcamp can be reduced by about fifty percent.

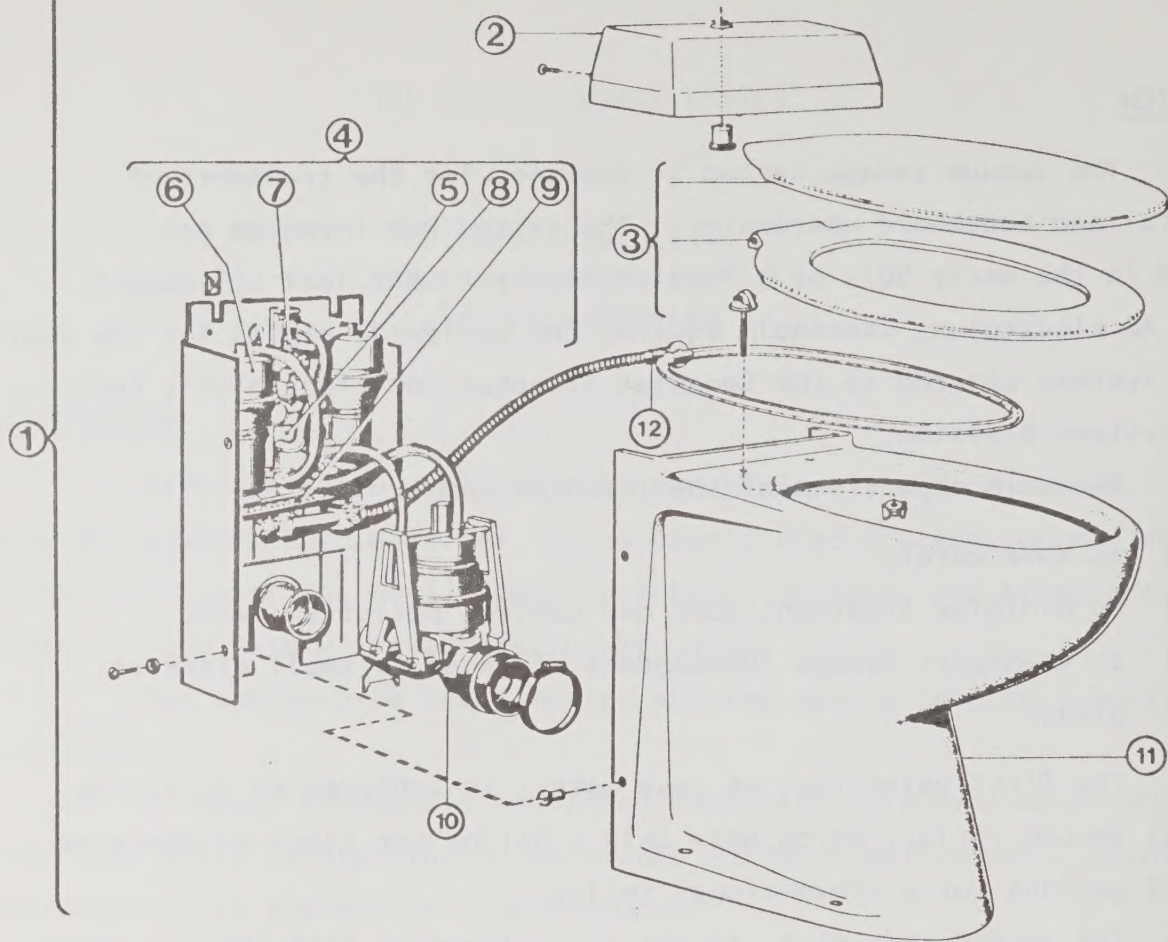
Controlling pollution can be further achieved by separating black water (from toilets and urinals) from grey water (from showers, handbasins, etc.).

The third objective is achieved by keeping the sewer system under vacuum. As the vacuum transportation is independent of grade, pipes can be laid horizontally or even upgrade within certain limits. Installation costs can be reduced:

- * to facilitate advanced building techniques by allowing small diameter pipes to be placed at random;
- * to provide more freedom in location and installation of fixtures; and,
- * to facilitate future changes with a greater freedom in design and installation.

FIXTURES

The vacuum toilet resembles, in its outward appearance, a conventional water closet without the tank.

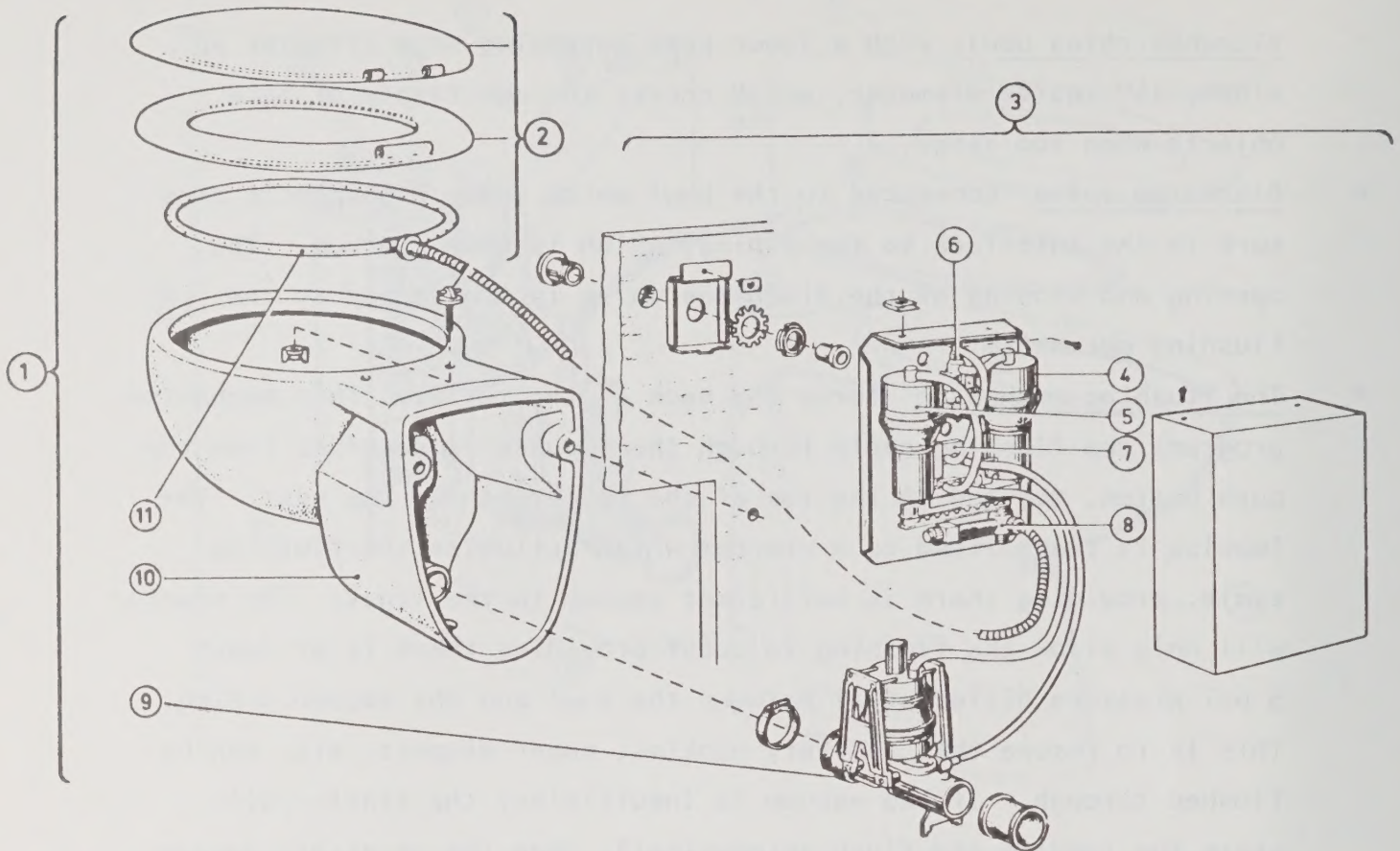


1. Vacuum toilet floor model
2. Cover
3. Seat
4. Operating mechanism
5. Discharge timer
6. Water timer
7. Starter
8. Distribution valve
9. Water valve
10. Discharge valve
11. China bowl
12. Flushing loop

FIGURE 1. VACUUM TOILET - FLOOR MODEL

The vacuum toilet consists of:

- * Vitreous china bowl, with a lower part narrowing to a circular 90° elbow, 1½" inside diameter, which checks the admittance of hard objects when too large.
- * Discharge valve connected to the bowl which under atmospheric pressure is the interface to the piping, which is under vacuum. The opening and closing of the discharge valve is controlled by the flushing mechanism.
- * The flushing mechanism forms the back of the toilet. This mechanism programs the flushing cycle through the impulse it receives from the push button, mounted on the top of the toilet behind the seat. The impulse is transmitted to a starter which activates the flushing cycle, providing there is sufficient vacuum in the lines. The starter will only allow the flushing to occur providing there is at least 5 psi pressure differential between the bowl and the vacuum piping. This is to insure that sanitary napkins, paper diapers, etc. can be flushed through. If the vacuum is insufficient the starter will store the impulse and flush automatically when the necessary vacuum is restored. The starter, through the manifold assembly, controls two timers. The timers control opening and closing of the discharge valve and the water valve.
- * The water valve controls the amount of water which enters the bowl from the spray ring located underneath the rim of the bowl. This spray ring sprays water at supply pressure through small holes down the side of the bowl and thereby completely rinses the bowl. Before the beginning of the flushing cycle, there is approximately 0.15 to 0.20 gallons of water in the bowl, an adequate amount to receive feces. This water will form a "water mirror" approximately 8" by 6". Flushing starts with the simultaneous opening of the discharge valve and the water valve. The contents of the bowl are pushed by atmospheric pressure into the piping, followed by approximately 3½ to 4 cu ft of air at atmospheric pressure. The fine spray of water from the water ring will rinse the bowl. After approximately 3 seconds the discharge valve closes, while the water valve continues to flow and fill the bowl to the required level. The water valve closes after



1. Vacuum toilet-wallhung model
2. Seat
3. Flushing Mechanism
4. Discharge timer
5. Water timer
6. Starter
7. Distributing valve
8. Water valve
9. Discharge valve
10. Chimbowl
11. Flushing loop

FIGURE 2. VACUUM TOILET - WALL HUNG MODEL

another 4 sec. The total flushing cycle has taken approximately 7 sec, and during this time admitted 1 quart of water and $3\frac{1}{2}$ cu ft of air into the system. The water valve is also a check valve and therefore is usually connected directly to the water supply. If required the water valve can be equipped with a vacuum breaker on the supply line as a positive prevention against siphoning. The water valve is always positively closed by the force of the lever arm, and therefore cannot leak.

The toilet discharges horizontally above the floor into a $1\frac{1}{2}$ " diameter pipe, via a rubber elbow or straight rubber connector. The toilet can flush vertically, up or down, to either side or straight back.

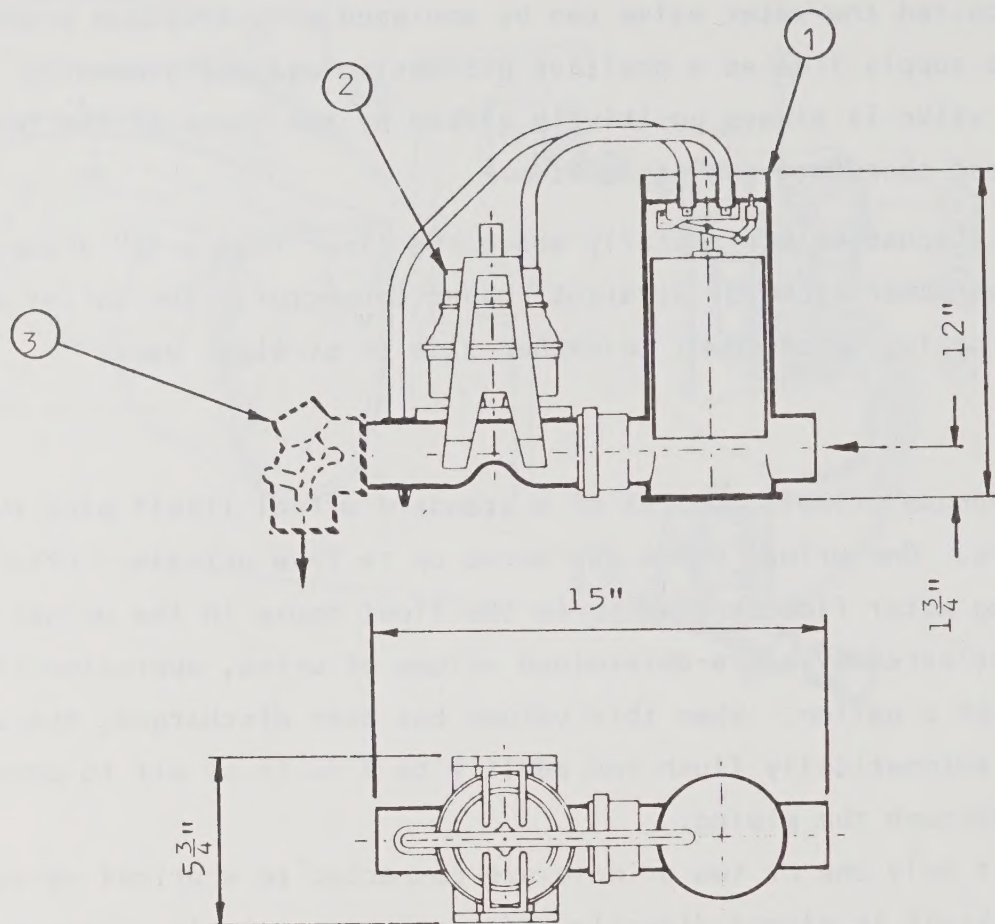
URINALS

Vacuum urinals consist of a standard urinal itself plus the urinal valve. One urinal valve can serve up to five urinals. Urine and flushing water flow by gravity to the float house in the urinal valve which is activated by a pre-determined volume of urine, approximately one fourth of a gallon. When this volume has been discharged, the urinal valve will automatically flush and admit $\frac{1}{2}$ to 1 cu ft of air to propel the urine through the piping.

If only one or two urinals are connected to a urinal valve and the valve itself is placed directly underneath the urinals, traps are not required. On the other hand, when several urinals are connected via a longer piece of pipe, 10 feet away or more, each urinal should be individually equipped with a trap, and the piping between the last urinal and the urinal valve should be vented to a $1\frac{1}{2}$ " pipe to prevent the liquid in the traps from being sucked out.

The urinal valve can also be connected to a trough-type urinal, in which case the urinal valve can be equipped to activate the water supply valve.

For arctic workcamps the urinals should be equipped with an adjustable flush valve which admits 1 pint to 1 quart each time it is activated.



1. Float Chamber
2. Discharge Valve
3. Rubber Connector

FIGURE 3. URINAL VALVE

GREY WATER VALVES

When smaller volumes of grey water are collected from five handbasins or less this is usually done via the urinal valve as described above.

Larger volumes are introduced into the vacuum system via a grey water valve. The grey water valve has the capacity of approximately $\frac{1}{2}$ gallon per second at 50 percent vacuum.

The air-to-water ratio of the grey water valve can be adjusted. The volume introduced at each automatic operation of the grey water valve can be determined by different layouts in the piping. The grey water valve is fully automatic and activated by the in-coming flow. It accomplishes transfer of grey water from the gravity fixtures to a vacuum main. Very often only one grey water valve per dormitory will be needed.

PIPING

In order to sustain the high velocity of transportation under vacuum and to maintain the integrity of the "liquid plug" for as long as possible it is desirable to use piping in the system that has as low a coefficient of friction as possible. Further consideration is to be made for the corrosive property of urine contained in the blackwater.

Of all types of material, plastic piping best fulfils the above conditions, at lower cost than other types of piping. In the far north, it may be more feasible to use copper nickel pipe, whereas pure copper pipe is less desirable with the high ammonia content of unmixed black water.

All fittings should be of long radius type, and all 45° , 90° , turns should only be made with long radius elbows. All 90° branch connections must be made with a combination of a 45° wye branch and a 45° elbow. A 2" DWV schedule 40 pipe has a capacity in excess of 400 flushes per hour; 3" DWV schedule 40 has a capacity of about 1000 flushes per hour.

In order to obtain good safety margins, the following limitations are normally applied:

- a) no more than five toilets on a $1\frac{1}{2}$ " pipe;
- b) no more than twenty-five toilets on a 2" pipe; and
- c) no more than one hundred toilets on a 3" pipe.

COLLECTION TANK

The collecting tank receives the sewage. If black and grey water are collected separately, two collecting tanks are used. The sewage is transported by the vacuum main. A part of the collecting tank serves the purpose of storing the sewage until it is removed for treatment or disposal, while the other part of the tank operates as a vacuum buffer thereby reducing vacuum pump starts and stops. The collecting tank is always under the same vacuum as the system. The tanks can be located above ground or buried. For black water systems only, no more than 250 toilets should be connected to each individual collecting tank. In determining the size of the tank, the following factors should be considered:

- a) Collection and storage only - The tanks are usually emptied by a scavenger truck. Generally speaking the storage capacity should not be less than the capacity of the truck in order to insure that the cost of emptying is kept to a minimum. In order to insure that the tank, for longer storage periods, does not turn septic, a solenoid valve is usually connected, admitting air, at certain intervals, into the tank.
- b) Discharge to existing sewers - If the tank, is only used as a transfer tank and sewage is being discharged to a near-by manhole, liquid level switches are located in the tank. The tank size should be of sufficient capacity in case of malfunction of the sewage pump to allow for repair or other means of disposal. For arctic conditions, where reliability and availability of the service might be significant, the discharge pump should always have a fully automatic stand-by pump. These pumps are of the torque flow type and are equipped with a totally recessed impellor.
- c) Discharge to treatment plant - When the tank is used to transfer sewage to a treatment plant, float switches are located in the tank to provide as steady a flow as possible over a 24 hour period. These levels can be easily adjusted to suit varying conditions. The tank capacity should be of adequate size to hold a peak flow while allowing sewage pumps to even out the flow to the treatment plant as required. Surge tanks can now be eliminated as this would only be a duplication

in tankage. The collecting tank can also be used in conjunction with a physical chemical plant to backwash filters thus eliminating the need for backwash pumps. The vacuum in the collecting tank can also do the job of other pumps, thus cutting costs further.

INSTALLATION AND TRANSPORTATION

The potential for vacuum sewer applications for temporary construction camps and municipal services is probably greatest in the northern areas of Canada, particularly in the arctic. The aforementioned is the major advantage of the vacuum system in the areas of water savings and the ability to transport wastewater economically where topography and soil conditions make gravity transport impractical.

Other advantages are that vacuum sewers are easy to install and are highly portable thus reducing shipping costs. In remote areas a large percentage of construction costs result from the cost of shipping and transporting materials to the worksite. The pipes used in vacuum sewers are of a small diameter and are considerably lighter than conventional sewer pipes. Consequently, shipping costs can be significantly reduced through the use of vacuum sewers.

Another important factor is the ease in which modules for workcamps can be constructed, since vacuum sewers can be installed on the same grade, thereby reducing the need for expensive site preparation to set up the workcamp on a grade. Since the pipes can run inside the buildings and therefore be installed prior to shipment, the amount of expensive northern man hours for installation can be reduced dramatically.

DISCUSSION OF WATER CONSUMPTION, SEWAGE DISCHARGE AND SEWAGE COMPOSITION

Workers on different projects, scheduled to go ahead in the Yukon and Northwest Territories, are well paid and well fed. When the temperature falls, appetites soar. BOD₅ and suspended solids of two to three times that of municipal waste have been measured. Work, north of the 60th parallel, is difficult. One of the reasons, is the high energy requirement. When inhaling air that has a temperature of 40°F below zero and exhaling it at 98°F above, the body has to generate an enormous amount of heat. This reason along with the excellent meals and low water

use may all contribute to the BOD_5 and TSS for black water being two to three times those reported in Table 1.

WATER USAGE

According to Edwards and Fahlman, "Work Camp Sewage Disposal Washcar-Incineration Complex" for the Environmental Social Program on Pipelines, average water consumption in construction camps has been rated by Fair et al (1966) at 45 U.S. gal per capita per day, but this includes kitchen consumption, drinking water, etc. A breakdown by the above authors of domestic urban water consumption apportioned the use as follows:

- a) 41% to flushing toilets;
- b) 37% to washing and bathing;
- c) 6% to kitchen use;
- d) 5% to drinking;
- e) 4% to washing clothes;
- f) 3% to household cleaning; and,
- g) 4% to miscellaneous activities.

It can be assumed that work camps today, fitted with conventional toilets would have a water consumption of roughly 50 gallons per man per day.

Assuming five to six visits per person per day to conventional toilets, discharging 4 to 5 gallons per visit, the following breakdown is assumed:

Sewage Flow - Conventional System

1.	Black water: 5-6 visit/day @ 4-5 gal/visit	= 25 gal
2.	Washing and bathing	10 gal
3.	Kitchen, etc.	8 gal
4.	Washing clothes & misc. activities	7 gal
Total flow		50 gal/c/d

Sewage Flow - Vacuum System

1.	Black water: 5-6 visit/day @ .25 gal/visit	= 1.5 gal*
2.	Washing and bathing	10 gal.

* Editor's note: This value does not include the volume contributed by the user.

3. Kitchen, etc.	8 gal
4. Washing clothes & misc. activities	7 gal
Total flow	26.5 gal/c/d

COMPOSITION OF SEWAGE

Not too many investigations of the composition of sewage have been carried out. Table 1 shows abstracts from an investigation by National Swedish Institute for Building Research, of an apartment building in Stockholm fitted with a vacuum system measuring pollutants from the kitchen, laundry, bathroom, and black water from vacuum toilets.

TABLE 1. COMPOSITION OF GREY WATER AND BLACK WATER FROM
APARTMENT BUILDING IN SWEDEN

	KITCHEN		LAUNDRY		BATHROOM		BLACK WATER	
	g/c/d	ppm	g/c/d	ppm	g/c/d	ppm	g/c/d	ppm
COD	37.5	662	7.0	872	6.5	109	72	8508
BOD ₅	17	324	3.0	349	4.5	76	20	2317
TSS	38.5	715	19	2240	20.5	356	53	6250
TOTAL P	.3	6.5	1.3	155	.6	103	1.6	190
TOTAL N	.6	11.4	.2	232	.3	5.6	11.0	1280
FLOW 1/c/d	51.0		8.5		63.0		8.5	

The figures for black water for the northern workcamps will most likely be two or three times as high.

Table 1 shows a very high amount of TSS as compared to BOD₅. The reason for the above is that the transit time in a black water sewage system is very short, and feces do not dissolve to the same degree as in a conventional gravity system. In the average black water collecting tank sludge forms at a rate of 0.12 litres (0.032 gallons) per person per day at the bottom of the collecting tank. If the solids can be collected separately from the bottom of the collecting tank, instead of remixing it with the remaining black water and adding to the relatively long

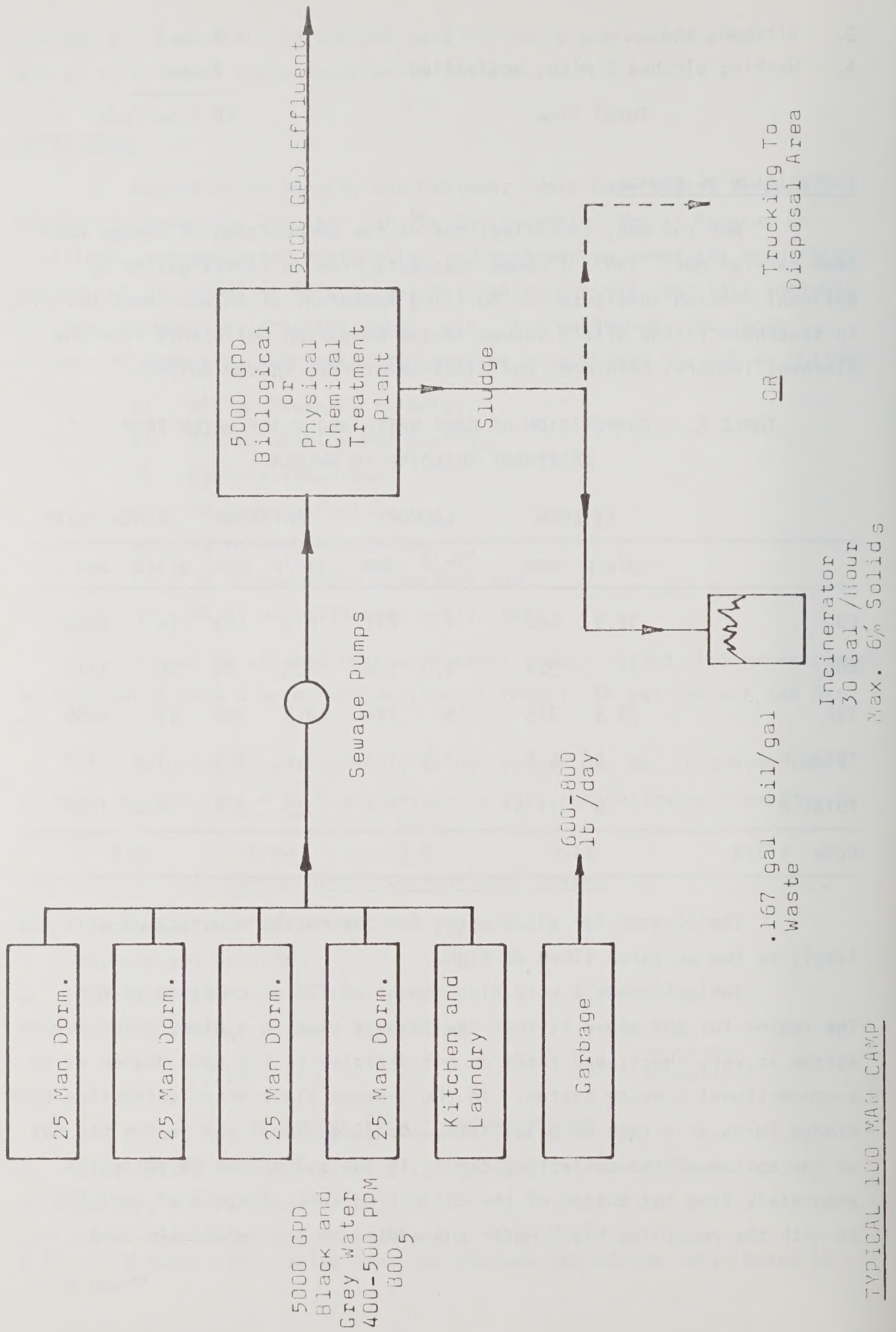


FIGURE 4. BLACK AND GREY WATER FROM CONVENTIONAL SYSTEM

treatment process in a biological or phys/chem treatment plant, the treatment process could be simplified.

TYPICAL 100 MAN CAMP (CONVENTIONAL SEWAGE SYSTEM)

In a 100 man camp, with a conventional sewage system, approximately 5,000 gallons per day of water has to be provided for the camp and treated for domestic use. The sewage will normally be pumped from the individual dormitories, kitchen, etc. by sewage pumps to a treatment plant. Since the hydraulic load, as well as the concentration of pollution varies, large surge tanks have to be incorporated in the treatment plant to allow for these variations to ensure a reasonably constant treatment.

A conventional system in a typical 100 man camp will have all structures placed on stilts to protect the permafrost. This often means that the piping has to be installed in the field, making installation costs soar due to the high cost of labor. Very often each individual dormitory will have a single sewage pump pumping to the treatment plant, meaning gravity transports sewage only part way.

TYPICAL 100 MAN CAMP (VACUUM SYSTEM, ONE PIPE)

Using a vacuum system, the fresh water requirements would drop from around 5,000 gallons per day to around 2,700 gallons per day. Each dormitory would be equipped with vacuum toilets, a urinal valve to handle urinals, an interface valve to handle showers, handbasins, washing machines etc. The vacuum system provides flexibility, in that utilidors can, to a certain degree, follow the terrain, and all piping in the dormitory can be above the floor, even for floor drains. The collected sewage can now be treated in a biological or chemical-physical treatment plant, with the sludge removed either by trucking or by incineration.

TYPICAL 100 MAN CAMP (VACUUM COLLECTION, TWO PIPES)

Black and grey water separately collected could be the ideal situation for work camps from fifty to one hundred-fifty men, and would require a total utility building, including water treatment system, black and grey water collecting tanks, a simple physical-chemical treatment plant

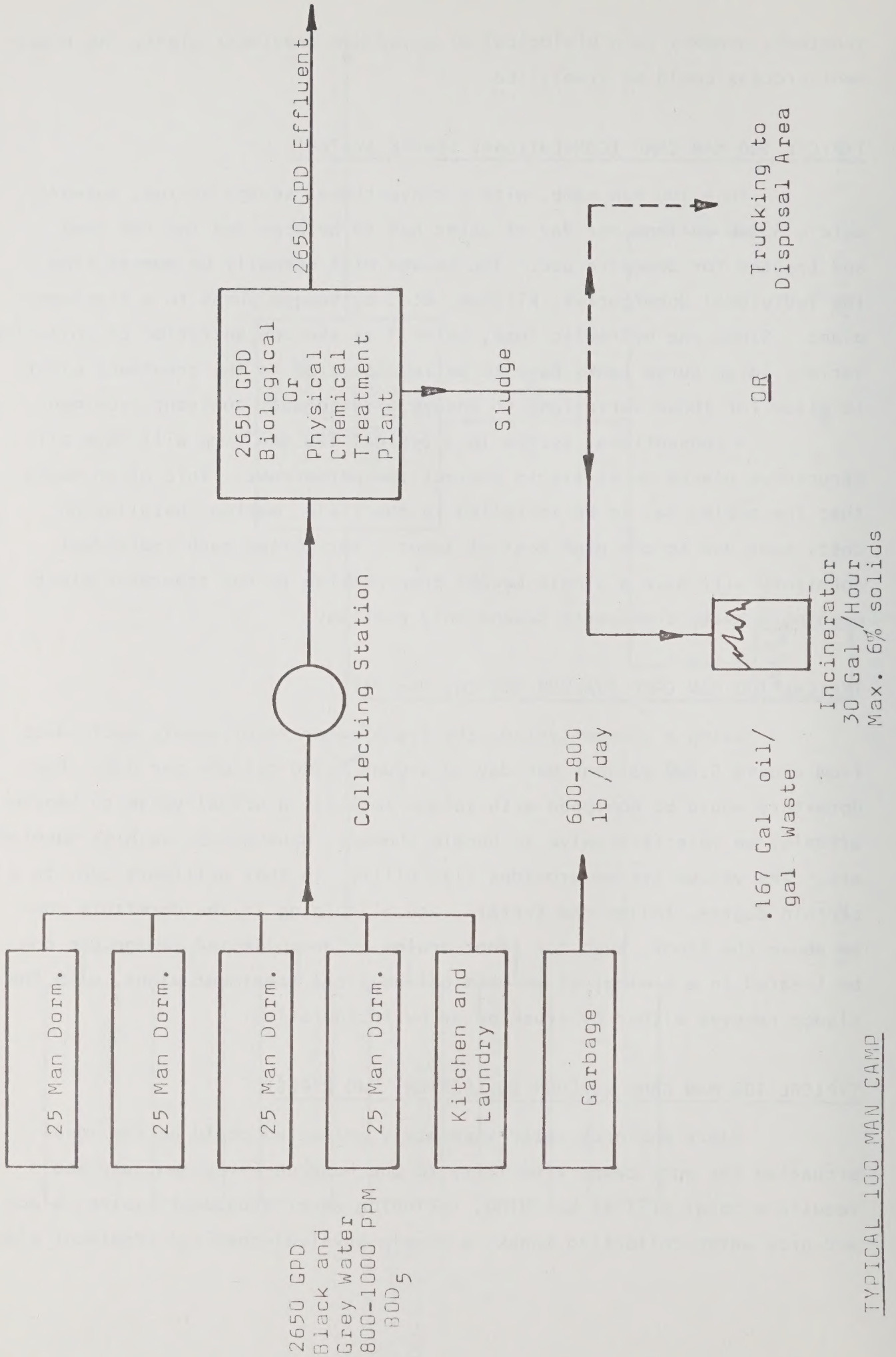


FIGURE 5. BLACK AND GREY WATER FROM VACUUM SYSTEM (1-PIPE)

TYPICAL 100 MAN CAMP

25 Gal /Man/Day Grey Water
1.5 Gal /Man/Day Black Water

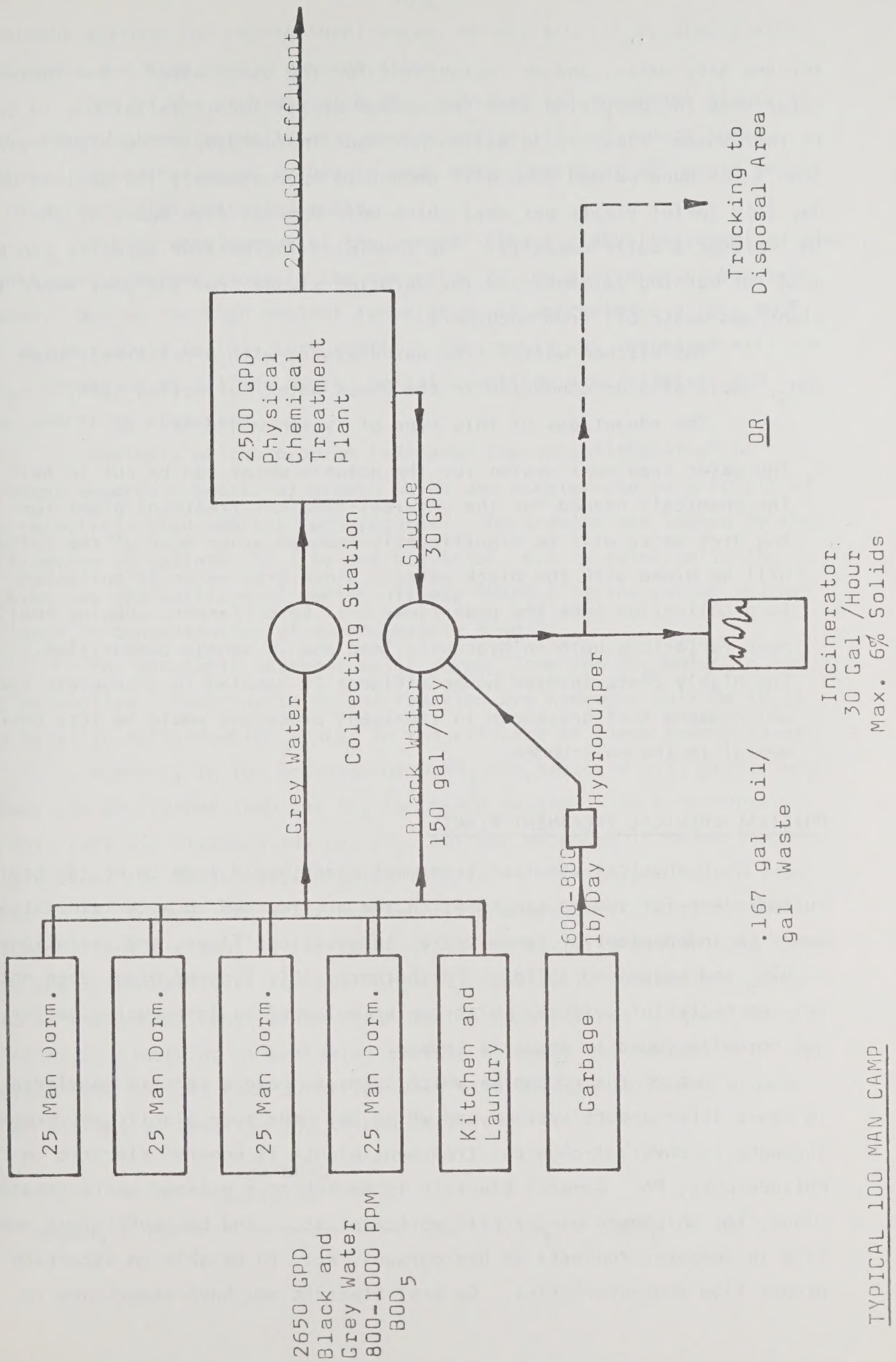


FIGURE 6. BLACK AND GREY WATER FROM VACUUM SYSTEM (2-PIPE)

TYPICAL 100 MAN CAMP

for the grey water, and an incinerator for the black water. One incinerator used in connection with the vacuum system for installations in Canada is the General Electric 30 gallon per hour incinerator. The black water from a one hundred man camp will amount to approximately 150 gallons per day (six toilet visits per day) which only demands five hours of the incinerator's daily capacity. The remaining incinerator capacity can be used for burning garbage, and incinerating sludge from the grey water treatment plant and waste oil from machinery.

The kitchen wastes from garburetors, with a relatively high BOD_5 , would also be connected to the black water collecting tank.

The advantages of this type of system would be:

- * The water treatment system for the potable water can be cut in half. The chemicals needed for the physical-chemical treatment plant for the grey water will be significantly reduced since most of the solids will be mixed with the black water. Since grey water is collected in a collection tank the peak flows will be different, showing smaller peak variations both in hydraulic load and in sewage composition.
- * The highly contaminanted human effluent is handled in a seperate system which means that breakdown in treatment processes would be less detrimental to the environment.

PHYSICAL-CHEMICAL TREATMENT PLANTS

A physical-chemical treatment plant would seem to be the best suited plant for sewage treatment in the arctic, and to a certain extent would be independent of temperature, inconsistent flows, and variations in BOD_5 and suspended solids. Furthermore, this type of plant does not rely on bacterial cultures which can be poisoned by introducing matter not normally found in domestic sewage.

One of the companies which seems to have a certain knowledge in basic life-support systems and which has made some significant breakthroughs in physical-chemical treatment plants is General Electric in Philadelphia, PA. General Electric is marketing a package waste treatment plant, for shipboard use, arctic workcamps etc., and has sufficient expertise in computer run-offs of hydrographs, etc. to be able to ascertain the proper flow characteristics. General Electric now have experience in

treatment systems for recreational areas, ships, etc., i.e. places with high peaks and high sewage concentration.

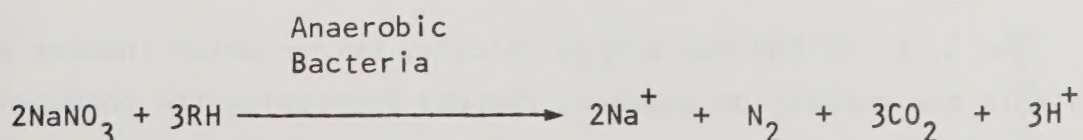
One of the problems with physical-chemical treatment plants is that carbon columns normally only have a design life of two to three months. Re-generation of carbon in work camps "north of 60" would result in relatively high operating costs.

During development of the General Electric physical-chemical plant, significant problems arose in the operation of the activated carbon sub-system. Due to the high ambient temperature of approximately 70 - 90°F, the columns would rapidly turn septic. The result was increased effluent BOD₅, formation of sulfide odors, metallic sulfide precipitates, and high operating pressures.

Analysis of the problem indicated the establishment of an abundant anaerobic bacterial growth which was accelerated as a result of the relatively high ambient temperatures. The problem was caused by the utilization of sulfate (SO₄) by the bacteria. G.E.'s solution to the problem was the addition of sodium nitrate (NaNO₃) to the carbon column influent in concentration of approximately 5 mg/l.

The anaerobic bacteria split oxygen from the SO₄ molecule for its metabolism. By-products of the reaction are hydrogen sulfide (H₂S) and metallic sulfide which appear in the effluent as black precipitates.

However, in the presence of NaNO₃ the bacteria will preferably attack the NO₃ rather than the SO₄ to obtain oxygen. The by-products in this case are nitrogen gas and CO₂, neither of which is objectionable. In addition, the dense matting which interferes with carbon column flow rates is not formed. As a further benefit, removal efficiency of the columns of soluble BOD₅ is increased since the bacteria use soluble carbon from the column effluent for cell growth. Apparently the bacteria enter into an endogenous respiration phase during some periods so that there is no gross sloughing of bacterial cells. Although the mechanics of the process have not all been quantitatively studied, the following scheme is an attempt to describe the column activity.



where RH is a soluble organic compound derived from the effluent.

The General Electric prototype columns have operated with sodium nitrate in excess of one year without a carbon change, and with no apparent drop in efficiency, although the design life was only intended to be three months. A useful life for the carbon, operating in this mode, is conservatively estimated at two years. The attached curve (Figure 7) shows data over one month that was obtained from a G.E. System, processing domestic waste with 200 mg/l BOD_5 and 300 mg/l TSS. The carbon column sub-system has been operating for 12 months with no carbon re-charge or makeup. The BOD_5 removal data resulting from the one-year evaluation suggests that this type of process, with NO_3 addition will have a significantly extended useful life before carbon activation or replacement is required.

Based on figures from the United States, with carbon columns delivered locally, a two year useful life of the carbon column will reduce the operating cost to 7 cents per thousand gallons, as opposed to 45 cents in a conventional carbon column.

Using a physical-chemical treatment plant similar to General Electric's in connection with the vacuum system, overflow from clarifier, column backwash, etc. can be automatically drawn into the vacuum collecting tank, thus eliminating the need for certain pumps and saving in capital costs and maintenance.

INCINERATORS

The vacuum system has been used in conjunction with incinerators, for black water incineration. The first installation was in combination with an Atlas Denmark sludge incinerator, in 1973 in Europe and here in Canada with a General Electric NV1850 sludge incinerator, in 1975.

Five naval installations, two for the Department of National Defence, and three for the Ministry of Transport, have been installed or proposed, to inject black water directly into a General Electric incinerator.

The G. E. NV1850 has a high velocity burner which induces a vortex action within the combustion chamber, thereby increasing the combustion contact time for better incineration of the injected sludge. The G.E.

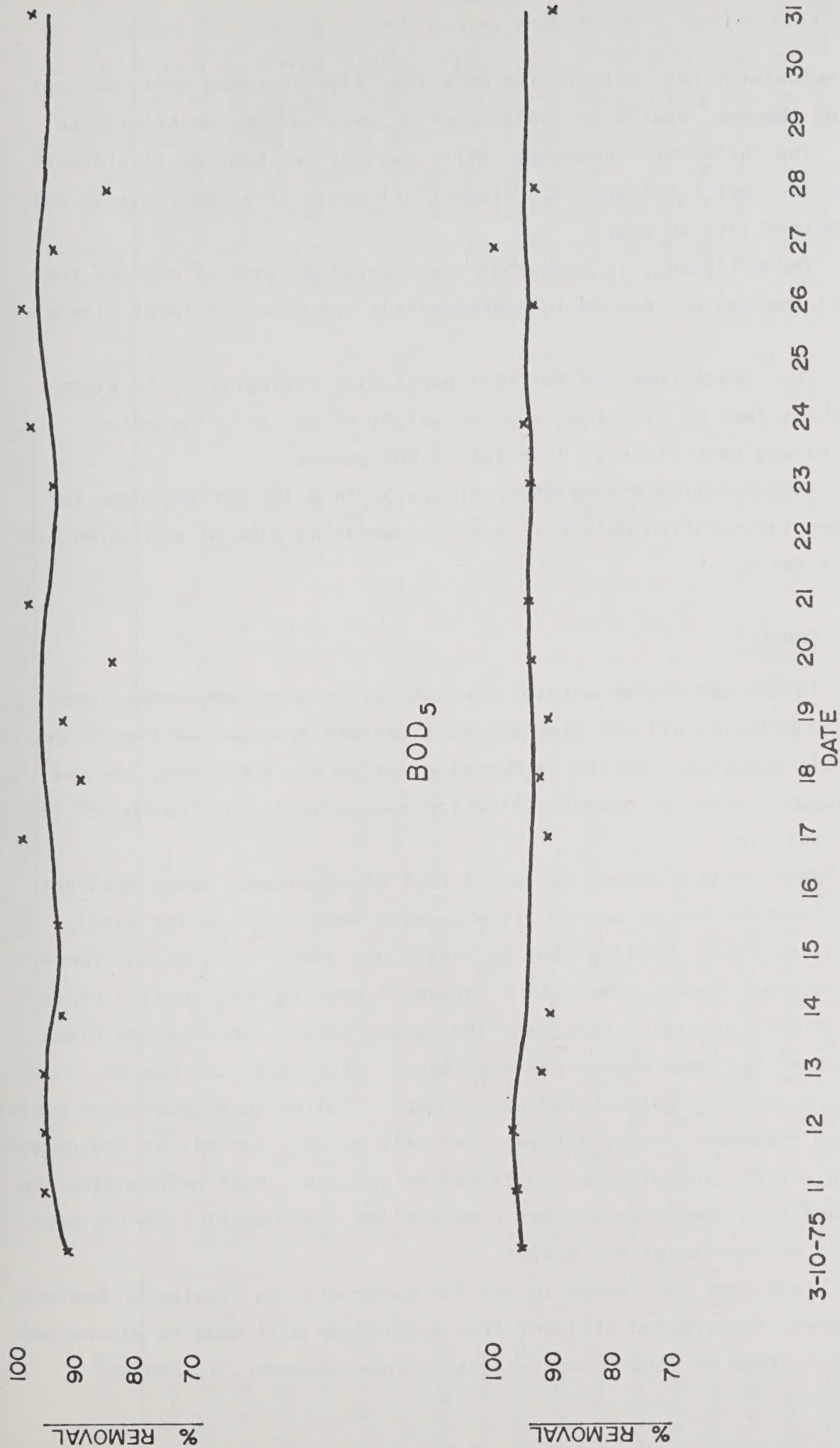


FIGURE 7. SYSTEM PERFORMANCE - GENERAL ELECTRIC PHYSICAL-CHEMICAL TREATMENT PLANT

NV1850 incinerator has operated for more than five thousand hours without combustion chamber repairs or replacement or even serious deterioration.

The incinerator consumes thirty gallons per hour of liquid with up to six per cent total solids. Sludge/fuel ratio is at best six to one, and guaranteed five to one.

The efficiency is such that one hundred gallons of noxious two percent sludge can be reduced to approximately one pound of inert mineral ash.

The space required for this particular incinerator, is eight feet by three feet by five feet and the weight of the unit including accessories and base plate is less than 2,000 pounds.

Incorporating the NV1850 incinerator in a 100 man workcamp for black water incineration only will mean an operating time of approximately five hours per day.

THE TOTAL CONCEPT

In the search for a total concept for northern workcamps, one must try to pinpoint all the problems in a certain area and arrive at the best overall solution. As far as domestic wastes are concerned, the use of the vacuum system for sewage collection can serve as the "backbone" for the total solution.

When using a vacuum system, a host of advantages seems apparent. Water requirements can be cut by fifty percent requiring smaller supply pumps, smaller pipes, smaller storage tanks, and lower heating requirements for water storage tanks. Now with a reduced sewage volume, smaller pipes can be utilized for transportation. The vacuum system can separate black and grey water for more economical treatment. Grey water can now be treated by a simple physical-chemical process. Solids such as kitchen wastes, sludge from treatment plant, garbage, and oily wastes, can all be incinerated with black water. Installation costs can be reduced. Most maintenance can be performed in a single area under a controlled environment allowing problems to be solved faster and easier.

Since most work camps in the far north will be located on bedrock or permafrost, the treated effluent from a workcamp will have to be discharged to a river, stream or lake in most cases. Since, however, it can be

TYPICAL LAND INSTALLATIONS AROUND THE WORLD

COUNTRY	PROJECT	#OF TOILETS - URINALS	TYPE OF INSTALLATION
U.S.A.	White Flint Corp. Maryland	300	Shopping center
U.S.A.	University of Michigan - Flint Michigan	80	Classroom Buildings
U.S.A.	South Sea Plantation - Captiva Island Fla.	80	Luxury Home Subdivision
U.S.A.	Wien Airline Deadhorse Alaska	15	Terminal Building
U.S.A.	Arco Prudhoe Bay - Alaska	114	Workcamp & offices
Australia	Goldsworthy Mining - Shay Gap W.A.	311	Mining town
Australia	Melbourne Harbour Trust Commission-Melbourne	77	Wharf Conversion
Bahamas	Geriatric Hospital New Providence	35	Hospital
Bahamas	Harold Road Subdivision Nassau	383	Lost cost houses
Bahamas	Anchorage Hotel	132	114 room hotel
Mexico	Ignacio M. Altamirawo Bld. Mexico	159	Low cost public housing
Denmark	Lynby Shopping Center Lyngby	300	Shoppingcenter and office
Denmark	Hummingen Falster	750	Leisure homes
Denmark	Idraettens Hus Copenhagen	26	Amateur sports hotel
Sweden	Ballinge by Ballinge	800	subdivision
Sweden	L.K.A.B. Svappavaraara	50	Iron ore mine
Sweden	A/B Volvo Torslanda	29	Truck factory
France	Marina de Talaris Lacanal	93	Leisure houses & marina
France	Hotel 'La Jamagi' Gerarmer	38	Hotel renovation
Germany	Karlskrow - Josepenburg Bavaria	250	rural subdivision
Holland	Beach of Cadzand Nieuwvliet Bresk.	48	Public toilet facilities
Finland	Lansiranniikon Voima oy Manttylovoto	42	Industrial Building
Finland	Ritoniemen Lomakyla vehmer salmi	72	subdivision

TYPICAL LAND INSTALLATIONS IN CANADA

PROJECT	LOCATION	# OF TOILETS- URINALS	TYPE OF INSTALLATION
Marine Industries Limited	Sorel, Quebec	4	Mobile rest room
Environment Canada	Fort Simpson, N.W.T.	2	Mobile rest room
Park Canada Resort	Tsawwassen, B. C.	10	Campsite
Alberta Baptist Camp	Caroline, Alberta	9	Recreational hotel
Min. of Natural Resources	Bronte, Ontario	6	Mobile rest room
Min. of Natural Resources	Bronte, Ontario	6	Mobile rest room
Min. of Natural Resources	Bronte, Ontario	6	Mobile rest room
Pacific Rim Resort	Vancouver Is., B. C.	66	2000 person campground
Waterfront Park	Toronto, Ontario	18	Public rest room
Lake O'Hara Lodge	Yoho National Park	27	Lodge and 19 cottages
Naval Test Establishment	Montreal, Quebec	4	Office & test facility
Ontario Hydro	Tiverton, Ontario	2	Mobile rest room
Min. of Natural Resources	Forest, Ontario	6	Mobile rest room
Ministry of Transport	Strathcona Sound, N.W.T.	5	Airport terminal bldg.
Pacific Rim National Park	Long Beach, B. C.	6	Portable rest rooms
Pacific Rim National Park	Long Beach, B. C.	6	Portable rest rooms
Greenpoint Campground	Ucluelet, B. C.	18	Public rest rooms
Heather St. Marina	Vancouver, B. C.	25	Live-a-boards in marina

assumed that in many cases the water supply for the work camp will come from the same source, and since nearly all the contamination, i.e. pathogenic bacteria, viruses, etc. is in the black water, the objections to using the recipient as a water source should be greatly reduced.

One thing for certain - the less water required, the less water to be transported and treated.

REFERENCES

"Arctic Waste Disposal", Environmental Committee Northern Pipeline, Report No. 74-10, 1974.

"The Electrolux - Liljendahl Vacuum Sewage System - Theory and Design", Hryniewicz, B. Chester, 1969.

"Household Waste Water", Olsson, Eskil, Karlgren, Lars, Tullander, Victor - The National Swedish Institute for Building Research, 1968.

"North of 60 Vacuum Sewer Systems", D.W. Averill and G.W. Heinke - Indian and Northern Affairs, 1974.

"Vacuum Sewage Systems, Possibilities for Improved Building Techniques and Simplified Site Organization", S., Horwitz, 1970.

"Watercraft Waste Treatment Systems Development and Demonstration Report" U.S. Environmental Protection Agency - 15020 DHG, Sept. 1971.

SESSION V

CASE STUDIES

SOME TECHNICAL ASPECTS OF THE ALASKA VILLAGE DEMONSTRATION PROJECTS

by

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INTRODUCTION

In 1970, the Congress of the United States enacted P.L. 91-224 Section 20 authorizing the establishment of the Alaska Village Demonstration Projects (AVDP) "to demonstrate methods to provide for central community facilities for safe water and the elimination or control of water pollution in those native villages of Alaska without such facilities." The authorization also included "...water supply systems, toilets, bathing and laundry systems, sewage disposal and other similar facilities." The legislation requires that, as a result of experience gained through the AVDP, recommendations be made regarding the provision of such facilities in all native villages of the state.

The villages of Emmonak and Wainwright were selected as locations for demonstration projects, and facilities have subsequently been provided at both locations. Figure 1 shows these project locations. Selection of villages to receive AVDP facilities was based upon independent study of a number of villages as well as advice and recommendations solicited from several regional native organizations and other government agencies. Small and intermediate size communities (population less than 500) are the focus of the AVDP. There are many such communities where provision of utilities has historically been difficult although the need is great.

The Alaska Village Demonstration Projects are administered by the U.S. Environmental Protection Agency (EPA) in the Agency's Office of Research and Development. Responsibility for the AVDP has been assigned to EPA's Arctic Environmental Research Station in College, Alaska.

Two comprehensive reports have been prepared describing the progress and outlining issues that must be resolved before a statewide program for providing similar facilities becomes feasible. The first report was submitted to Congress in July 1973; the second is in draft form (March 1976).

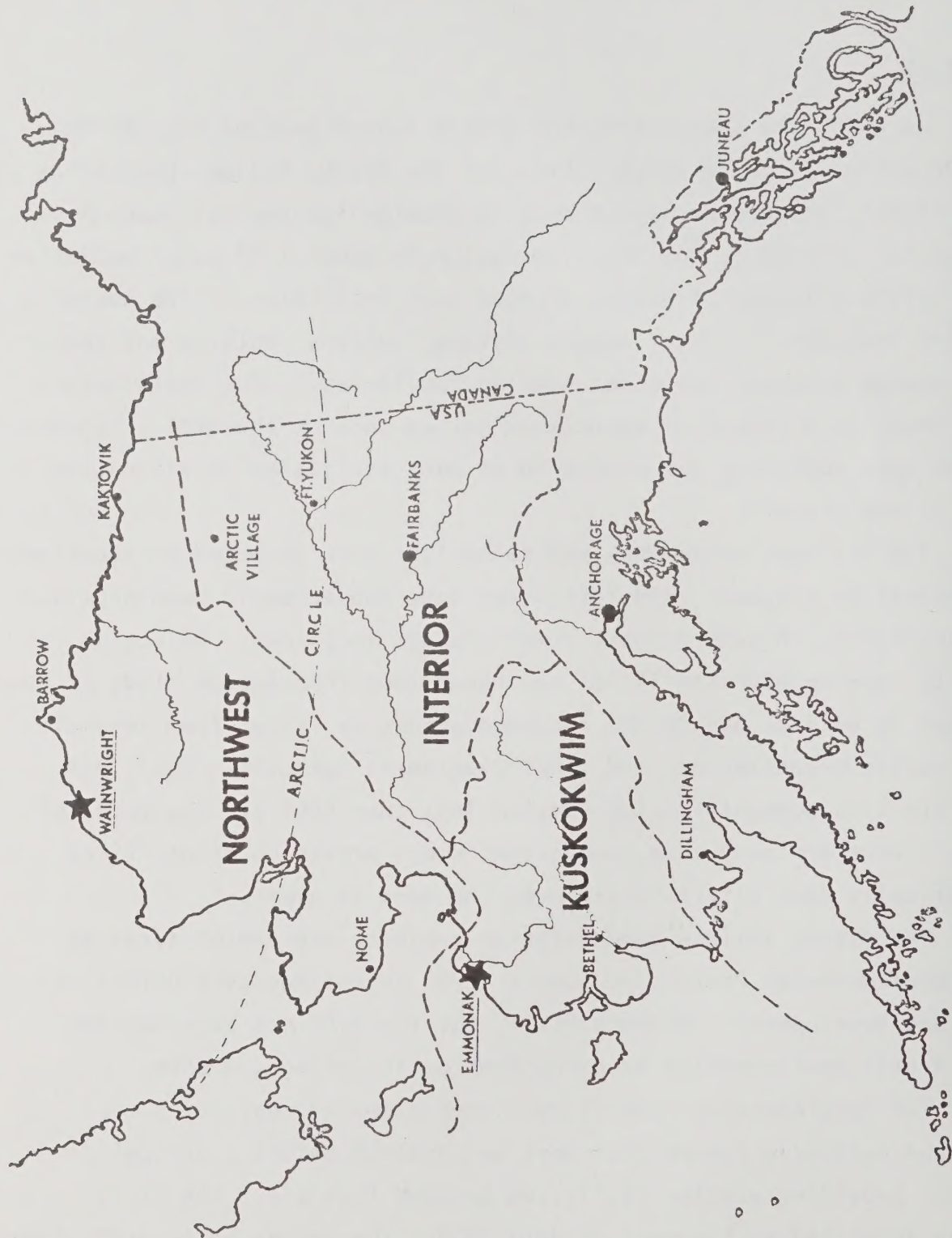


FIGURE 1. MAP OF ALASKA SHOWING LOCATIONS OF WAINWRIGHT AND EMMONAK

This paper provides the design rationale for the AVDP at Wainwright, Alaska. It includes discussion of the concept, economics, engineering design and projections for similar successor projects.

BACKGROUND

Wainwright is an Eskimo community of 375 people located on the coast of the Arctic Ocean ($70^{\circ}38'N$ lat.; $160^{\circ}02'W$ long.) about 145 km (90 mi) southwest of Barrow. Administratively, Wainwright is within the North Slope Borough which is responsible for providing certain municipal services.

Wainwright was founded about 70 years ago. Many residents are descendants of the original settlers. A map of Wainwright appears as Figure 2.

Traditionally, the people of Wainwright live by subsistence. Caribou and sea animals are the major foods. In the past, trapping has provided a minimal cash income to the Village.

The climate at Wainwright is typical of the arctic coastal area. Annual average temperature is $-12^{\circ}C$ ($10^{\circ}F$) with January temperatures averaging $-27^{\circ}C$ ($-16^{\circ}F$) and July temperatures averaging $6^{\circ}C$ ($43^{\circ}F$). Mean annual precipitation is approximately 10 cm (4 inches) which includes an annual average of 51 cm (20 inches) of snowfall. Wind prevails from the northeast causing significant snow drifting and windchill. There is continuous sunlight from late April to mid-August. In the winter, between late November and late January, twilight is the only natural light. Coastal ice usually begins to form early in October and breakup occurs in late June or early July. Total direct solar radiation received by a three-dimensional object ranges from over 2.11 MJ/m^2 (2000 BTU/ft^2) on June 22 to 0 on December 22. At equinox (March 21) solar radiation is approximately 0.95 MJ/m^2 (900 BTU/ft^2). Building design criteria for the area are as follows:

Wind load 146 kg/m^2 (30 psf)

Snow load 146 kg/m^2 (30 psf)

Seismic probability -1 (3.0 to 4.5) minor structural damage

Heating degree days 12 ,000 $^{\circ}C$ days (21,000 $^{\circ}F$ days)



Wainwright is underlain by continuous permafrost. The active zone above permafrost varies somewhat depending upon exposure but does not exceed 1 m (39 inches) and averages approximately 0.5 m (20 inches). Soil has a high ice content with both ice wedges and ice lenses occurring in many places. The ground surface, where undisturbed, consists of natural tundra mosses and grasses. No vegetation in the area grows to a height of more than 0.5 m (20 inches). The ocean and river beaches in the area are a source of sand and fine gravels ranging in sizes up to about 6 mm (1/4 inches).

Topography of the area is very gently rolling ground which shows typical polygonal pattern of high moisture content fine grained soils in permafrost areas. A natural embankment approximately 3 m (10 ft) high exists along the beach. From the beach cliff the ground slopes gently upward to a high point approximately 0.5 km (0.3 mi) inland which is at an elevation of nearly 15 m (50 ft) above sea level.

Sub-bituminous coal with thermal value of approximately 22 kJ/g (9500 BTU/lb) is found in significant quantities in the area. A limited amount of residential heat is provided by coal which has washed ashore. In the early years of the century, whaling ships collected coal at out-croppings in the river bank about 22 km (14 mi) up river from Wainwright. A limited drilling program has disclosed the presence of coal seams ranging from 1 to 4 m (3.5 to 14 ft) thickness underlying the entire area at a depth of about 9 m (30 ft).

It is suspected that both oil and natural gas underlie the area although no exploratory work in the immediate area of Wainwright has been performed. The U.S Navy is currently preparing to do extensive exploration work on Naval Petroleum Reserve No. 4 (PET 4) which surrounds Wainwright.

Because of the isolation, construction costs are much higher than in the contiguous United States or in the more accessible regions of Alaska. Virtually all construction materials must be shipped in. Wainwright is more than 5000 km (2700 nautical mi) by surface shipping routes from Seattle. Airline distance from Fairbanks is 725 km (450 mi). Surface shipping costs from Seattle to Wainwright range up to \$660 per metric ton (600 per short ton). Air shipping costs between Fairbanks and Wainwright by scheduled commercial carrier is about \$615 per metric ton (\$560 per short ton) and charter freight haul is in the same range of cost.

Related construction costs in Barrow and Wainwright are 3 to 3.5 times higher than those in Seattle. Not all of the inflated construction cost can be attributed to freight charges. The high risk due to weather uncertainties during the short construction season and the expense of importing skilled labor to remote areas combine to increase costs.

Communication may be made by either of two separate telephone lines. Unfortunately neither is dependable, thus rendering voice communication uncertain. Scheduled mail flights arrive at Wainwright twice each week under good conditions. Mail is dependable but slow.

Passenger transportation to and from Wainwright is by air. The village has a lighted 600 m (2000 ft) unpaved landing strip which can accommodate aircraft as large as DeHaviland "Twin Otter". Heavier aircraft occasionally use the 100 m (3500 ft) runway at the Distant Early Warning (DEW) station approximately 11 km (7 mi) away from the village. Any materials or personnel landed at the DEW station must then be transported cross-country to the village. Regular sea lift shipping is accomplished once each year by the U.S. Bureau of Indian Affairs ship U.S.M.S. Northstar III. Barge lift to Wainwright from Kotzebue and Nome is available on a charter or contract basis during the open water season each year.

The resident labor force in Wainwright is quite limited. Trades represented are the same as those found in large cities except that the reduced opportunity for workers to engage in their respective crafts leaves their techniques somewhat unpolished and less sophisticated than is normally expected of journeyman level craftsmen.

Wainwright was selected as a project site because of its location in the true arctic and its homogeneous and fairly stable population. The advice of regional native organizations was sought and considered in arriving at the selection. The arctic location was desired because of the adverse conditions imposed by climate and remoteness since a successful demonstration under harsh conditions would likely prove equally successful under less adverse circumstances.

Between September 1972 and February 1973 a central community facility was built at Wainwright. The facility was opened to the public in late February 1973 and quickly gained popularity and acceptance. In November 1973 fire destroyed the facility. Subsequently, the decision was made to construct a replacement in Wainwright. The new facility will

include many of the features of its predecessor and will incorporate changes which were indicated as desirable as a result of observation of the original facility.

The original Wainwright facility was described in detail in a previous paper [1]. Other references to and details of the original system at Wainwright were presented in the "Report to Congress, Alaska Village Demonstration Projects" in July 1973.

PROJECT CONCEPT

One reason for the establishment of the AVDP is the lack of sufficient water of good quality to permit healthful living conditions in most Alaskan native villages. In addition, the lack of a satisfactory means of waste disposal is nearly universal in these villages. Improvement in this area of need is another objective of AVDP.

Two approaches to these problems have been used by other agencies in the past. The simplest is to provide a central watering point where each family may pick up and transport the water for home use. The other end of the water service spectrum is the fully piped pressurized potable water system designed to provide about 190 l per capita daily (50 gpcd)* along with the wastewater collection systems required for disposal of wastewater from each home. However ideal the latter system may appear, there are numerous reasons for attempting to trade off some of its advantages against its major disadvantage, namely cost.

The simple approach provides initially safe water but cannot assure the arrival of safe water in the home since distribution is not part of the system. Moreover, the chore of carrying water to the home tends to discourage the use of adequate quantities of water for the maintenance of health and hygiene.

The piped distribution system in its usual configuration is expensive to construct and maintain, particularly in cold climates, and assumes the availability of large quantities of water. There has been no evidence that the use of such large quantities of water is actually beneficial or that a smaller quantity might not be equally adequate under some conditions.

* Nationwide, water used in U.S. homes approximates the quantity
 $Q = 333 + 98.4 P$ where Q is litres/day and P is the number of persons.

When large quantities of water are available, such as in the urban areas of the United States, there is a tendency to be wasteful of this valuable resource.

The AVDP is based on the concept that the water-related needs of a small northern Alaska community can more economically be met if people do their laundry and bathing at a central facility. This reduces the volume needed in the homes to a fraction of the usual amount and permits major reductions in the size and costs of the distribution system. Under conditions such as exist at Wainwright, vehicular distribution of water and similar collection of wastewater becomes feasible. Such an approach would be quite impractical if large volumes of water were required in the homes.

It is estimated that water for laundering and bathing comprises 35% of the total need. By eliminating the standard flush toilet, home water use can be reduced another 45%. Thus, by gaining public acceptance, services which were previously impractical can be made available and an adequate amount of potable water can be available for use in the home.

In summary, then, the concept of the AVDP embraces the notion of conservation of water to a high degree, thereby allowing scaled down and consequently less expensive equipment.

DESIGN

Specific design requirements were established prior to the design exercise. The design requirements for the Wainwright facility are presented in the appendix.

Preliminary investigations at Wainwright indicated that water could be obtained from a shallow tundra lake approximately 2.7 km (9,000 ft) southwest of the village. This water could be expected to be of good quality during the summer when no ice is on the lake. At other times the water contains higher concentrations of organic materials and is undesirable.

It was determined that a 3.8 Ml (1,000,000 gal) storage tank should be built near the project site to store water for winter use. This alternative was chosen for the following reasons:

1. Construction, operation and maintenance of a year-round pipeline to the lake would be more expensive than the tank and water would be of lower quality.

2. Desalinization of sea water or water from the adjacent brackish estuary of the Kuk River would require a pipeline and distillation equipment which would be more expensive than the tank to construct, operate and maintain.

3. Ice harvest would be less expensive to initiate but would be significantly more expensive to operate and maintain.

The Indian Health Service (IHS), USPHS, contributed very significantly to this phase of the project. They were influential in the selection of storage approach and subsequently designed and constructed the storage tank. IHS also provided the vehicles for the distribution system and the vehicle maintenance building.

In making these judgements, the annual sum of capital costs plus operation and maintenance costs, can be used to indicate the most desirable (least expensive) economic alternative.

The 3.8 MI (1,000,000 gal) volume was determined to be adequate if water conservation tactics were employed. The allocation of water for design purposes was as follows:

Personal use at home	6.8 kl (1800 gpd)
School	3.8 kl (1000 gpd)
Showers	4.2 kl (1100 gpd)
Laundry	2.8 kl (750 gpd*)

*Laundry water is recycled and does not draw from the storage tank.

Water saving devices employed to accomplish these goals are numerous. The largest single saving is through avoidance of the standard water flush toilet. Further reduction is achieved by flow and time regulated showers which minimize water used for bathing. Sauna baths are also provided which satisfy the need for a "hot soak" without the use of water. Toilets in the central facility use a combination of air and treated graywater for flushing while those in the school are of the recycling type such as those used in aircraft.

Water and wastewater treatment equipment were specified which would treat the required volume during the normal working day and thereby reduce the possibility of malfunction during periods when the facility is unattended. A schematic plan of the graywater system is shown in Figure 3.

Conservation of energy was an important design consideration. Energy cascade and heat salvage are employed where practical. This allows for significant savings in operation of the facility.

Space and water heating are provided by a central liquid phase heater using an organic fluid as the primary heat transfer medium. Where lower temperatures or water contamination hazard exists, a secondary heat transfer fluid (propylene glycol/water mixture) is used. Heat is recovered from the exhaust stack of the diesel electric power generation set in the integrated heating system. Building ventilation incorporates a heat exchanger designed to extract heat from the exhaust air and pre-heat fresh intake air.

Facilities for public use in the central building are showers, saunas and laundry. Approximately 110 m^2 (1200 sq ft) are occupied by these facilities. The laundry contains four industrial grade washing machines which can handle in excess of 9 kg (20 lb) of dry clothing. The machines are large enough to launder sleeping bags, small rugs, parkas and other heavy articles. Showers are coin operated and automatically shut off after a preset period. The public facilities are located on the second floor of the building so that space may be efficiently utilized and gravity drainage from showers and laundry may be employed. A plan of the public area is shown in Figure 4.

OPERATIONAL EXPERIENCE AND EVALUATION

The original Wainwright facility had been well constructed and its performance met expectations in most regards. It was in operation for eight months prior to the fire. Operational data for this period consist of accurate facility use records and periodic performance evaluations conducted in the process of fine tuning the potable water plant and during the modifications in optimizing performance of the graywater treatment components.

1. Potable Water Treatment

Because of the relatively high quality of the raw water only minor adjustments of the potable water treatment plant were required. It was concluded that chemical addition for coagulation purposes was probably superfluous. This finding was taken into account in the design of the

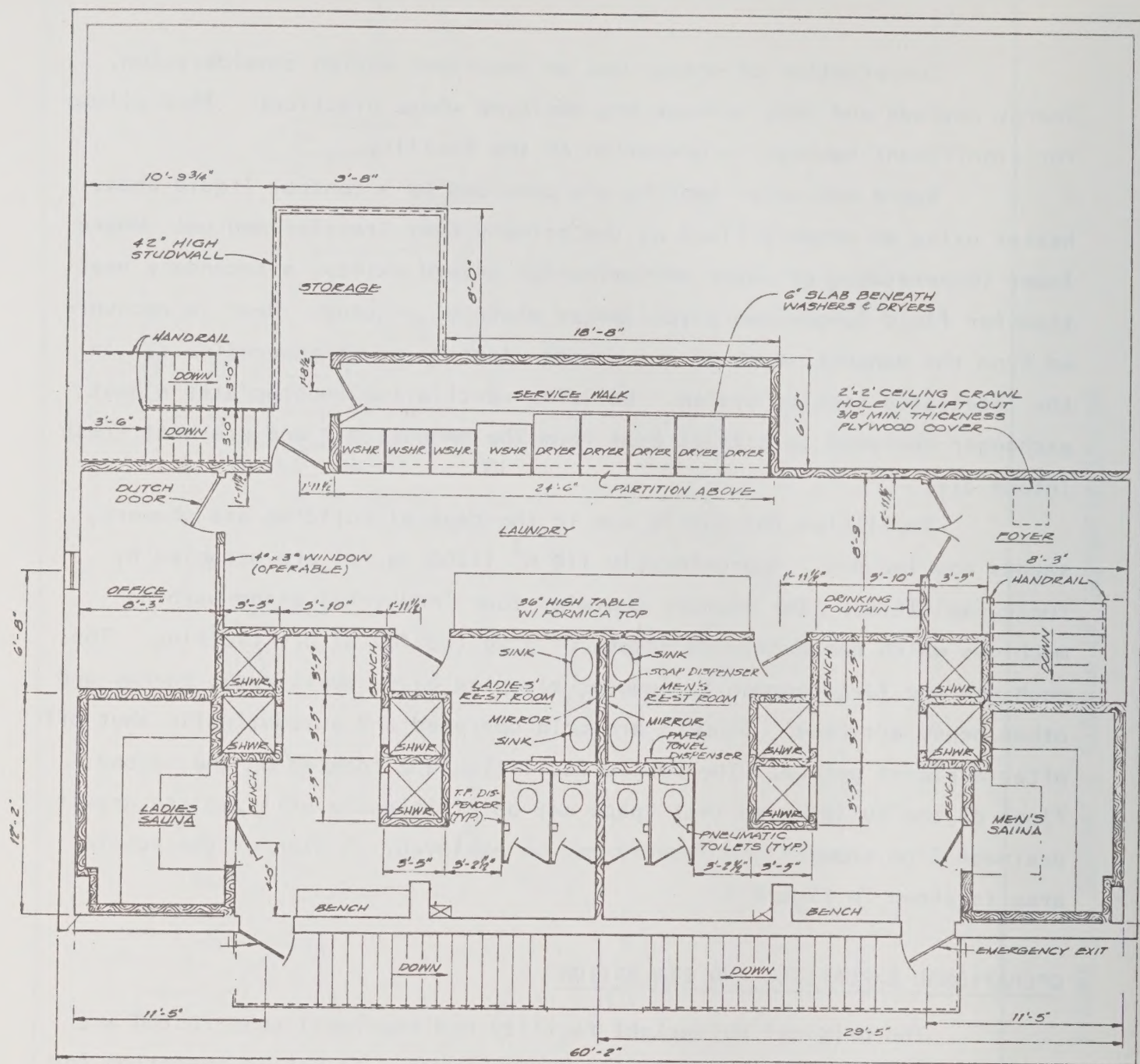


FIGURE 4. PLAN OF PUBLIC AREA IN WAINWRIGHT FACILITY

replacement plant which will produce potable water by means of filtration, carbon adsorption and chlorination only.

2. Graywater Treatment

Performance of the graywater plant proved sensitive to influent temperature fluctuations. Plant upsets occurred about every six weeks. Occasionally, graywater production from washers and showers exceeded the combined capacity of the treatment unit and of the graywater storage tank, 4.5 kl (1200 gal), and thereby interrupted service.

Plant upsets caused by biological growth and decomposition in accumulated sludges occurred in spite of disinfectants applied to the system. Wastewater entering the graywater holding tank was dosed with a quaternary ammonium compound, known by the name "Roccal," at about 50 mg/l. This compound was rated as a very efficient disinfectant. Lime used in the upflow clarifier during operation to achieve $\text{pH} \geq 11$ was also considered to be a fairly effective disinfectant. Finally, chlorine was applied to the product water at about 10 mg/l to maintain a chlorine residual >1.0 mg/l after 1 hour contact in the treated water holding tank. Despite such routine disinfection measures, the system would occasionally foster biological growths, and the only means of correcting the problem was to start over with clean water and clean tanks.

From the beginning, the upflow clarifier failed to perform adequately. Performance was characterized by massive floc carry-over into the recarbonation chamber and other downstream tanks. An extremely wide range of chemical dosages was tried in an attempt to achieve good performance of the upflow clarifier. At all dosages large quantities of sludge carried over into downstream vessels.

Concurrent with sludge carryover from the upflow clarifier, sludge buildup in the chemical mixing chambers of the "Clearflow" unit was observed. This problem could temporarily be remedied by pumping out all five sections on a regular and frequent basis but this proved to be difficult and unsatisfactory. Because of "Clearflow" construction, it was impossible to remove all of the accumulated sludge which eventually became septic and infected downstream tanks and processes.

A more satisfactory solution to the "Clearflow" sludge accumulation problem was obtained by by-passing the chemical mixing chambers and

using the influent pipe as a combination mixing chamber and distribution header. After a period of operation, however, sludge still accumulated in the chemical mixing chambers due to hydraulic pressure and again became septic resulting in plant upset.

To prevent further upset due to upflow clarifier or recarbonation chamber sludge accumulation, plumbing was arranged to completely by-pass the upflow clarifier and the recarbonation chamber which were then left dewatered.

In October 1973, the wastewater treatment system was revised in the field to provide for greater ease of operation and better performance. The baffle plate between the sedimentation tank and chemical mixing chambers was removed entirely. This permitted withdrawal of sludge from the entire area subject to accumulation and was expected to prevent future upsets attributable to sludge accumulation.

Mixing in the influent pipe seemed to improve the system. By use of different polyelectrolytes, performance was even further enhanced.

The modified system, however, was not yet without problems. The upflow clarifier and recarbonation chambers had previously acted as thermal buffers to absorb some of the shock of hot waste water from the laundry and showers which was not applied directly to the "Clearflow." Convection currents in the sedimentation/flocculation chamber were observed to reduce the clarification efficiency in the "Clearflow."

The hydrasieve never performed according to expectations. Its primary value would have been in its ability to remove relatively large suspended particles from normal sewage. Since the facility did not process sewage per se, this advantage was not realized. Because all of the graywater was pumped to the graywater storage tank, most of the lint and hair was incidentally removed by becoming lodged in pump impellers. Other solids, such as silt and sand, were too small to be retained on the hydrasieve. Process sludge was too weak to be retained on the screen and was automatically re-introduced into the system.

To avoid the several problems connected with the hydrasieve, a pump with a basket-type strainer was installed at the laundry sump. The strainer of this pump was very effective in removing laundry lint and preventing pump impeller clogging and lint collection in the graywater tank. Process sludge was withdrawn continually from the sedimentation hopper

of the "Clearflow" unit by a pump and fed to the centrifuge. This procedure proved to be superior to the former arrangement.

Figures 5 and 6 permit comparison of the graywater treatment system before and after modification.

At the time of the fire, the graywater treatment system plant still required frequent operator attention and could not be left running by itself overnight. It operated in a sufficiently stable manner, however, for a formal performance monitoring program to begin. Between May and October 1973 data were collected at five different times at the end of field trips when the plant was operating well. The results, as summarized in Table 1, do not reflect the effect of plant upsets.

Coliform bacteria were detected in the effluent following periodic plant upsets. It is felt, however, that no personal contamination from this source resulted since the laundry used predominately hot water which destroys coliforms and some pathogenic organisms.

Bacterial contamination was the primary threat to the validity of the water re-use concept. Very low numbers of coliforms by themselves are not significant, but accompanied by background growth of unidentified types and perhaps by viruses, these microorganisms could become a health problem. In addition to careful disinfection, regular monitoring of coliforms has been identified as a definite requirement of any water reuse system. Virus monitoring is not yet a tool applicable to field use in small plants.

Recycle water-use records were destroyed in the fire. Computations based on the number of loads washed, showers taken, etc., indicate that water was reused in the laundry about 2-1/2 times before final treatment and discharge.

3. Blackwater and Sludge Incineration

In the absence of a vehicular blackwater collection system, the only toilet wastes available for incineration were from the six recirculating chemical toilets in the public section of the plant. Mixed with water treatment sludges, these were vacuum collected and fed into the incinerator via a positive displacement pump. Liquid-solids separation caused some clogging of the feed pipe. Fuel required to incinerate the blackwater sludge mixture was about 1 gal per 4 gal treated.

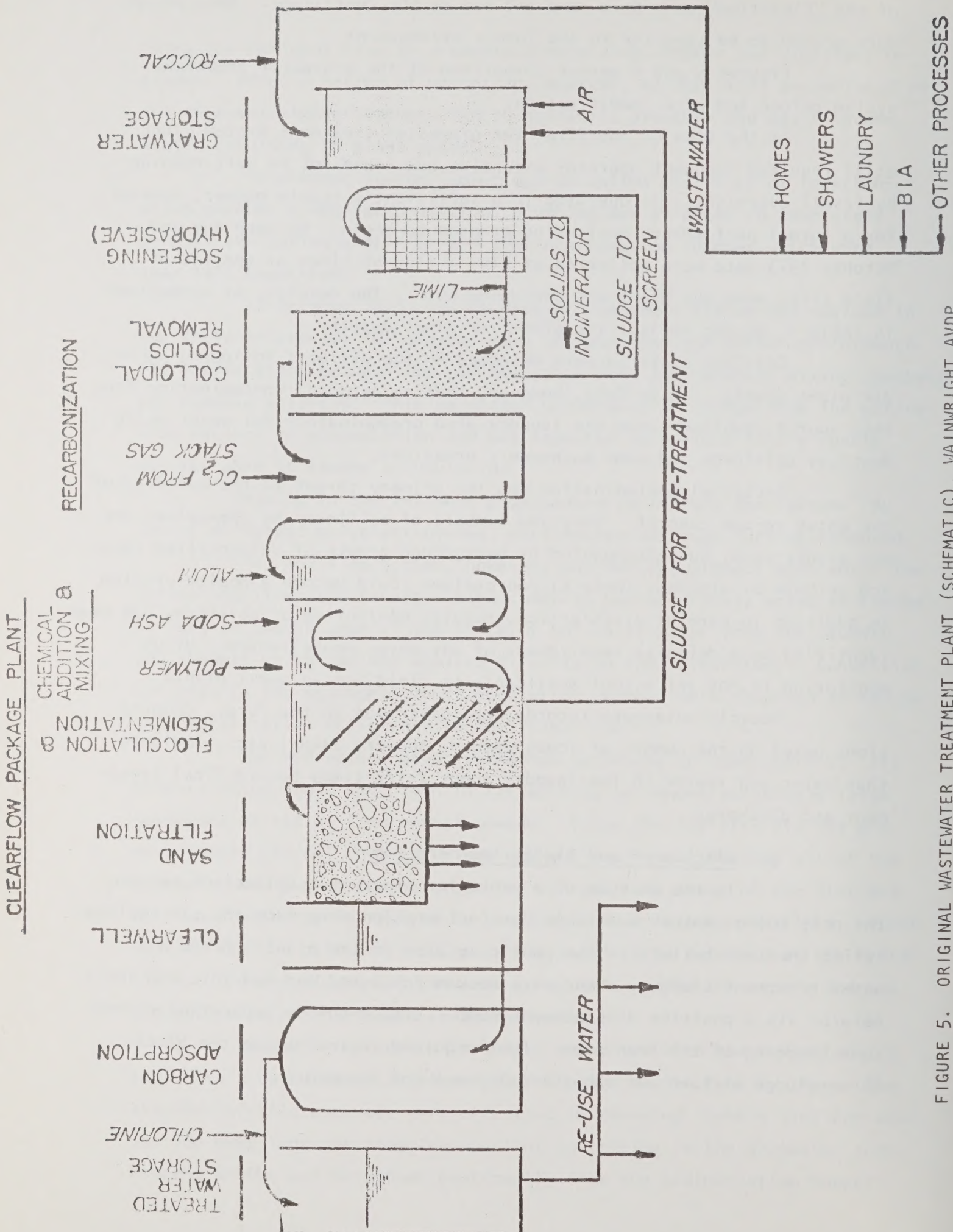


FIGURE 5. ORIGINAL WASTEWATER TREATMENT PLANT (SCHEMATIC), WAINWRIGHT AVDP

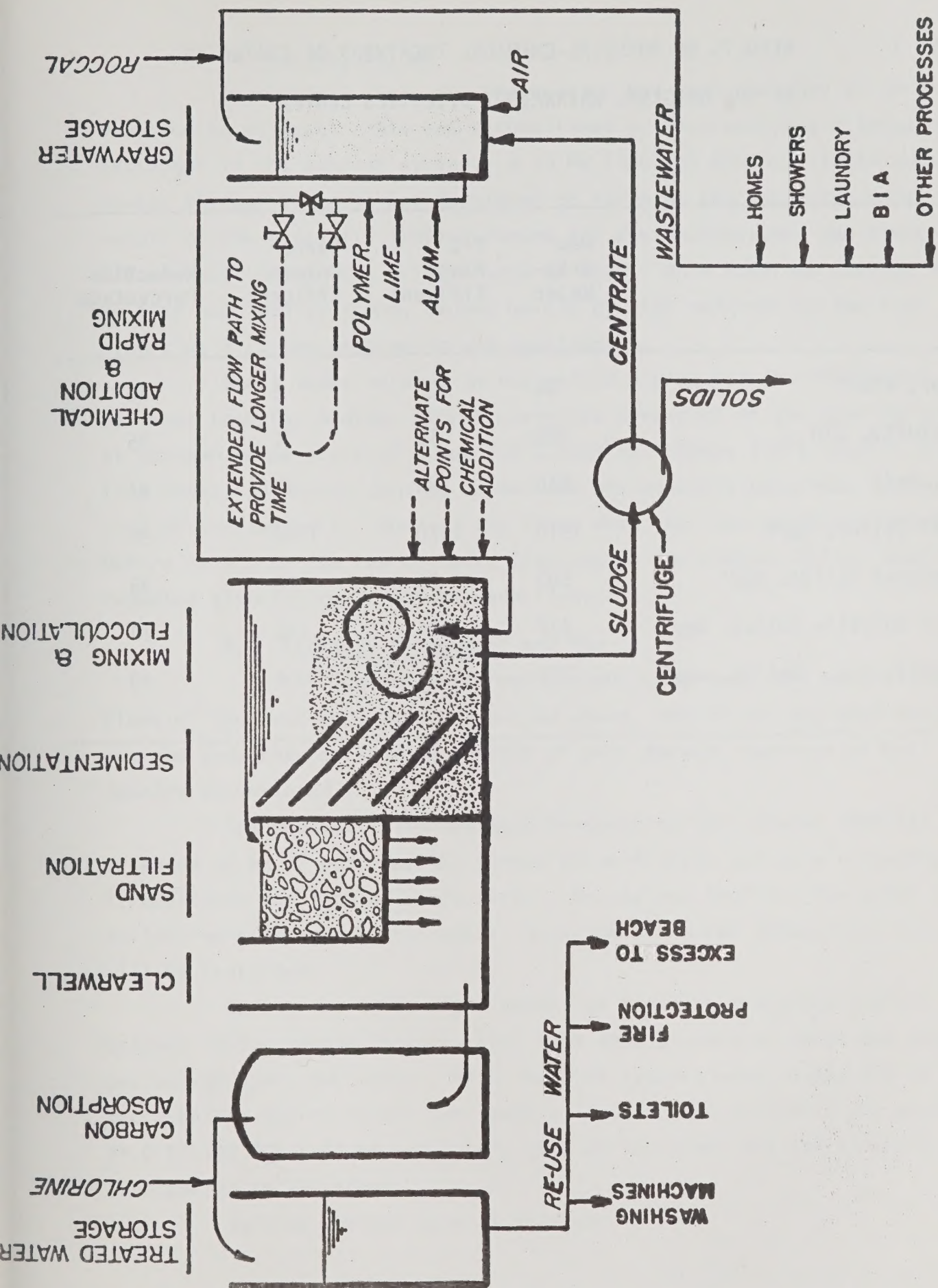


FIGURE 6. MODIFIED WASTEWATER TREATMENT PLANT (SCHEMATIC), WAINWRIGHT AVDP

TABLE 1 RESULTS OF PHYSICAL-CHEMICAL TREATMENT OF GRAYWATER
AT THE ORIGINAL WAINWRIGHT UTILITIES CENTER

	Raw Gray- Water	P-C Plant Effluent	Carbon Column Effluent	Reduction Percentage
Color, PCU	35	25	5	86
Turbidity, JTU	200	16	10	95
COD, mg/l	840	284	25	97
Total Solids, mg/l	1910	1670	1240	35
Suspended Solids, mg/l	503	25	10	98
Total Volatile Solids, mg/l	624	304	162	74
Volatile Susp. Solids, mg/l	281	16	4	99

4. Heating System

To conserve fuel, the incinerator had been designed to serve as main source of heat. This was accomplished by incorporating a large heat exchanger in the exhaust system. A 14 MW (400,000 BTU/hr) liquid phase heater (Singer VaPower) was furnished to serve as the auxiliary unit. As a result of the initially limited demand for the incinerator, the Singer VaPower unit became the prime source of heat. Once numerous startup difficulties had been overcome, caused mainly by high moisture of the fuel atomizing air, the unit performed excellently.

Small leaks existed in the welded piping for the "Thermal 55" heat transfer medium. These prevented operation of the heating system at optimum temperature of about 177°C (350°F). Above 110°C (230°F) oil from leaks vaporized, causing bothersome and possibly hazardous contamination of in-plant air. Some of the leaks were too inaccessible to reach. Others came from the few threaded fittings in the system, which, despite repeated efforts, could not be made tight.

5. Facility Management and Use

The washers performed without problems. Due to the limitations of the heating system, discussed above, the dryers operated below optimum temperature. During periods of peak demand, backlogs of wet laundry accumulated.

The pneumatically operated Monogram toilets (Model 160M-PA) appeared to be of poor design, proved to be fragile and were virtually irreparable for lack of spare parts. In the new facility low water use toilets manufactured by Microphor, Division of Harrah Industries, Inc., will be installed.

During the first eight months of facility operation (March-October 1973), people in Wainwright took 4650 showers or about one shower per person every two weeks. 4370 loads of laundry were washed and dried, representing approximately two loads of laundry per household per week. 94.6 kl (25,000 gal) of water were sold at the plant and individually transported to the homes.

Service charges were as follows:

Shower, 2 minutes	25 cents
Load of wash	50 cents
Dryer, unit time	10 cents
Drinking water, per liter	0.79 cents
Sauna	Free

Plant income for the period was \$5,700.

After the fire, village water consumption climbed steadily, despite a city council decision in February 1974, to raise water prices from 0.79 cents to 1.59 cents per l (3 cents to 6 cents per gal) for water sold at the tank. The charge for water delivered to homes via the Bombardier all-terrain tanker vehicles, which became available in mid-February 1974, was set at 2.11 cents per l (8 cents per gal). This rate remained in effect until January 30, 1975, when the price of delivered water was adjusted downward to 1.06 cents per l (4 cents per gal). The reason given for this change was that the water in the tank had gotten stale, was without treatment, and therefore was not worth the higher cost. In May 1975, the price of water delivered to institutions such as the school and businesses was increased to 1.59 cents per l (six cents per gal), on the assumption that these institutions could better afford to pay closer to the real costs of the service than the average householder at Wainwright.

Consumption of water appears to have been unaffected by these changes in costs. It has increased steadily, taking a quantum jump when the tanker vehicle began to make deliveries in February 1974. Peak demand in the homes occurs during the months of June through September. This may be because some households continue to get some of their water from ice in winter. The history of water sales at Wainwright is graphically shown in Figure 7.

Since November 1973, the facility has been operated by the city council under a cost-reimbursable contract. During the first 22 months of the contract period, total expenditures were \$77,000. This figure does not include fuel which has been shipped via the Alaska Air Command COOL Barge. Income was \$29,000 for the same period: \$21,700 from sale of water and \$7,300 for hauling wastewater from the school.

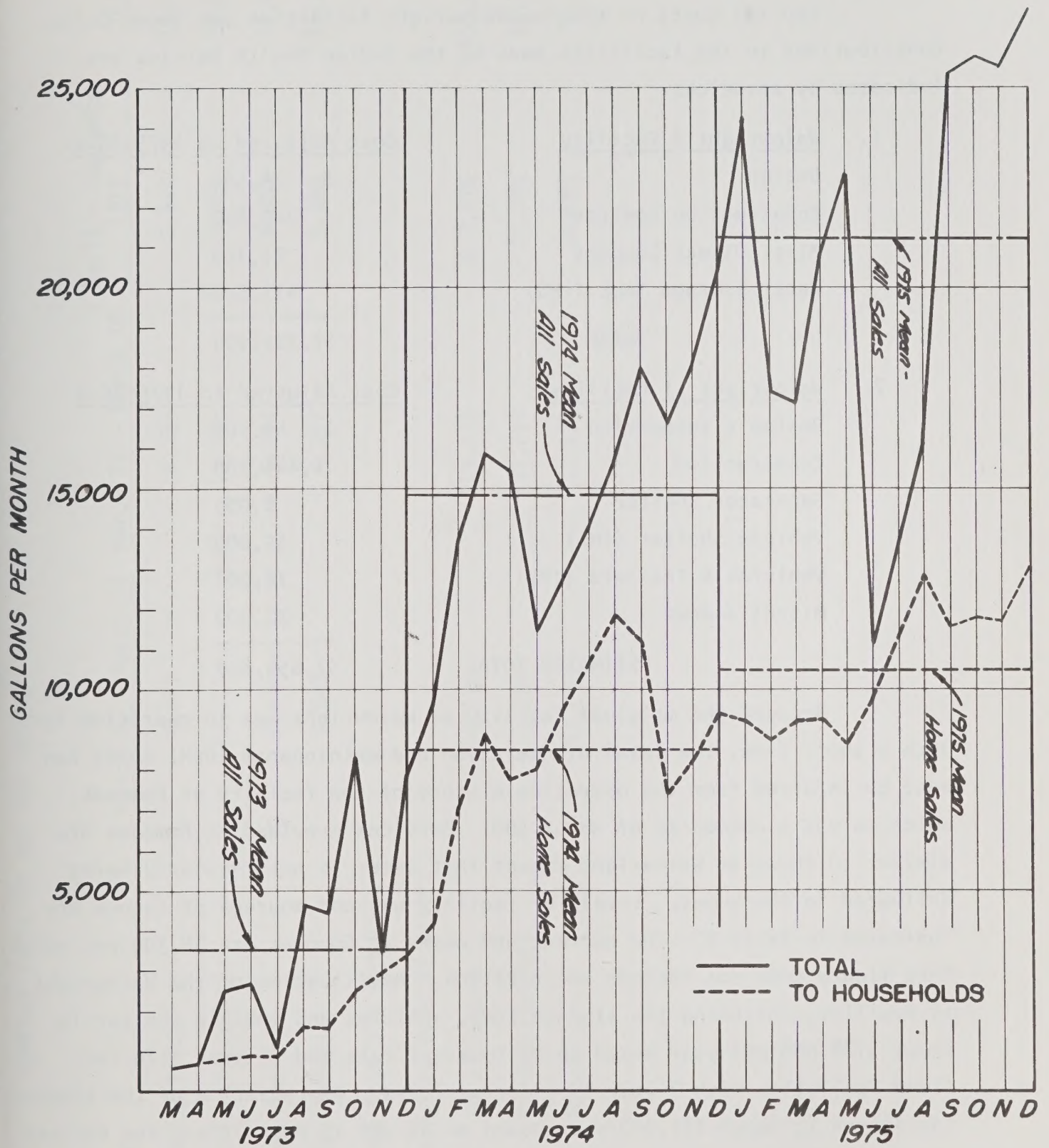


FIGURE 7. WATER SALES AT WAINWRIGHT

PROJECT COSTS

Capital costs of the two Wainwright facilities are shown below. Contributions to the facilities made by the Indian Health Service are indicated by astericks.

1.	<u>Wainwright I Facility</u>	<u>Cost Adjusted to 1975-76 \$</u>
	Design	\$ 74,500
	Construction Contract	715,800
	Misc. Direct Support	21,100
	Water Storage Tank (IHS)	411,500*
	TOTAL	\$1,222,900
2.	<u>Wainwright II Facility</u>	<u>Cost Adjusted to 1975-76 \$</u>
	Design & Inspection	\$ 49,500
	Construction	1,445,700
	Generator Shelter	8,000
	Vehicle Shelter (IHS)	55,600*
	Vehicles & Trailers (IHS)	76,000*
	Miscellaneous	20,000
	ESTIMATED TOTAL	\$1,654,800

Because the original facility at Wainwright was in operation for such a short time, the level of operation and maintenance (O&M) costs can best be inferred from the operating history of the facility at Emmonak, which serves a community of about 500. Services provided at Emmonak are similar to those at Wainwright except that water is not regularly being delivered to the homes. Levels of facility use and sources of income are indicated in Table 2. The current O&M costs at Emmonak are \$6,300 per month. This figure does not include amortization. Amortization of the Wainwright II facility, including the storage tank, vehicles and vehicle shelter is about \$188,000 per year based on 8% interest rate and 25-year life for fixed facilities with 7-year life for vehicles. Amortization of the Emmonak facilities is about \$91,000/year based on 8% and 15-year life. The current average monthly income is \$3,700. At present, the difference is paid by the Environmental Protection Agency under a cost-reimbursable contract with the community. The gap between income and cost can be expected to narrow

TABLE 2. EMMONAK FACILITY USE AND INCOME

Category	March 73 - March 74		March 74 - March 75		April - September 1975	Total
1. Washers, loads	4,761		6,131		3,920	14,812
2. Dryers, time units	12,117		13,065		9,022	34,204
3. Baths, men	6,435		6,643		4,353	17,431
4. Baths, ladies	3,543		4,551		3,248	11,342
5. Income from all services, including sale of water:						
a. To villagers	\$15,136		\$19,632		\$17,476	\$52,244
b. To institutions	1,954		12,791		11,385	26,130
c. Total	\$17,090		32,423		28,861	78,374

at Emmonak because of that community's viability as a fishing center, and at Wainwright through use of locally available coal for generation of power and heat. In both communities public institutions such as the schools, that are furnished services, would have to absorb a major portion of treatment costs. On a wider, statewide basis, establishment of water-related utilities which meet current and projected treatment standards will require financial support from the state or federal governments for maintenance and operation.

The above costs are substantial and the question arises whether such federally sponsored central community facilities are costing more than they should. The recent establishment of commercially sponsored communities at Prudhoe Bay makes possible some comparisons. Atlantic Richfield Company (ARCO) and Exxon have made available capital and operating cost information for the sewage treatment and water treatment plants in their joint operations center on the North Slope. Before mid-1975, the design size of these plants was comparable with that of the AVDP facilities. They served a population of 300 to 400 people in a boarding house type arrangement.

As of December 1, 1974, gross investment in the ARCO-Exxon Operations Center water and sewage treatment plants was \$1,173,021 and \$1,026,754, respectively, making a total of \$2,199,775. Amortized at 8% for 25 years, this is about \$206,000 per year. Building plumbing fixture costs are not included. Yearly gross operating costs are reported as follows:

	<u>1972</u>	<u>1973</u>	<u>1974</u>
Water Treatment	\$131,000	\$162,400	\$147,200
Sewage Treatment	74,900	121,000	120,500

Neither property taxes nor prorated Anchorage office administrative support costs are included. Average monthly operating costs thus come to \$12,240 for water treatment and \$8,790 for treatment of sewage. The total average monthly costs of operating the Emmonak AVDP facility (\$6,300) compares favorably with the above. AVDP capital costs have also generally been lower.

VEHICULAR DISTRIBUTION SYSTEM

Vehicles for the Wainwright system were provided by the U.S. Public Health Service. The vehicles are Bombardier "Muskeg Carriers" powered by 66 kW (88 bhp) Perkins Diesel engines. Two primary vehicles and two tracked trailers were provided. Figure 8 shows the water distribution vehicle.

The primary vehicle designated for water delivery has a chassis mounted enclosure which houses a 1325 l (350 gal) tank and the equipment necessary for filling and discharging. A schematic diagram of the system is presented in Figure 9. This system is similar to two trailer mounted systems used for hauling graywater and blackwater.

Two reasons will be suggested for using a pneumatic system rather than a pump. The first is that draining a pump during a prolonged idle period might be overlooked resulting in freezing and breaking the pump housing. Secondly, blackwater and graywater may contain solids which would clog a pump resulting in a messy and unsanitary maintenance routine. Since there are three tank units it was felt that all three should be similar for purposes of uniformity and to eliminate the possibility of confusion.

In Wainwright a procedure for water delivery has been worked out whereby water customers receive delivery of potable water to their home holding tanks upon request. At the present time most of the home holding tanks are make-shift containers. Newer homes built under the auspices of the Alaska State Housing Authority (ASHA) will be equipped with specially designed water storage and waste holding tanks.

Two delivery men are employed to deliver water and work an average of three hours per day. It is anticipated that when the Wainwright II system is completed and operational, the delivery system will be adequate for the village. Current demand by the school for relatively large volumes of vehicle-delivered water will be met by a small utiliduct and thereby relieve the vehicles for increasing demand for home delivered water.

Graywater and blackwater collection are accomplished in a manner similar to water delivery using separate containers for each substance.

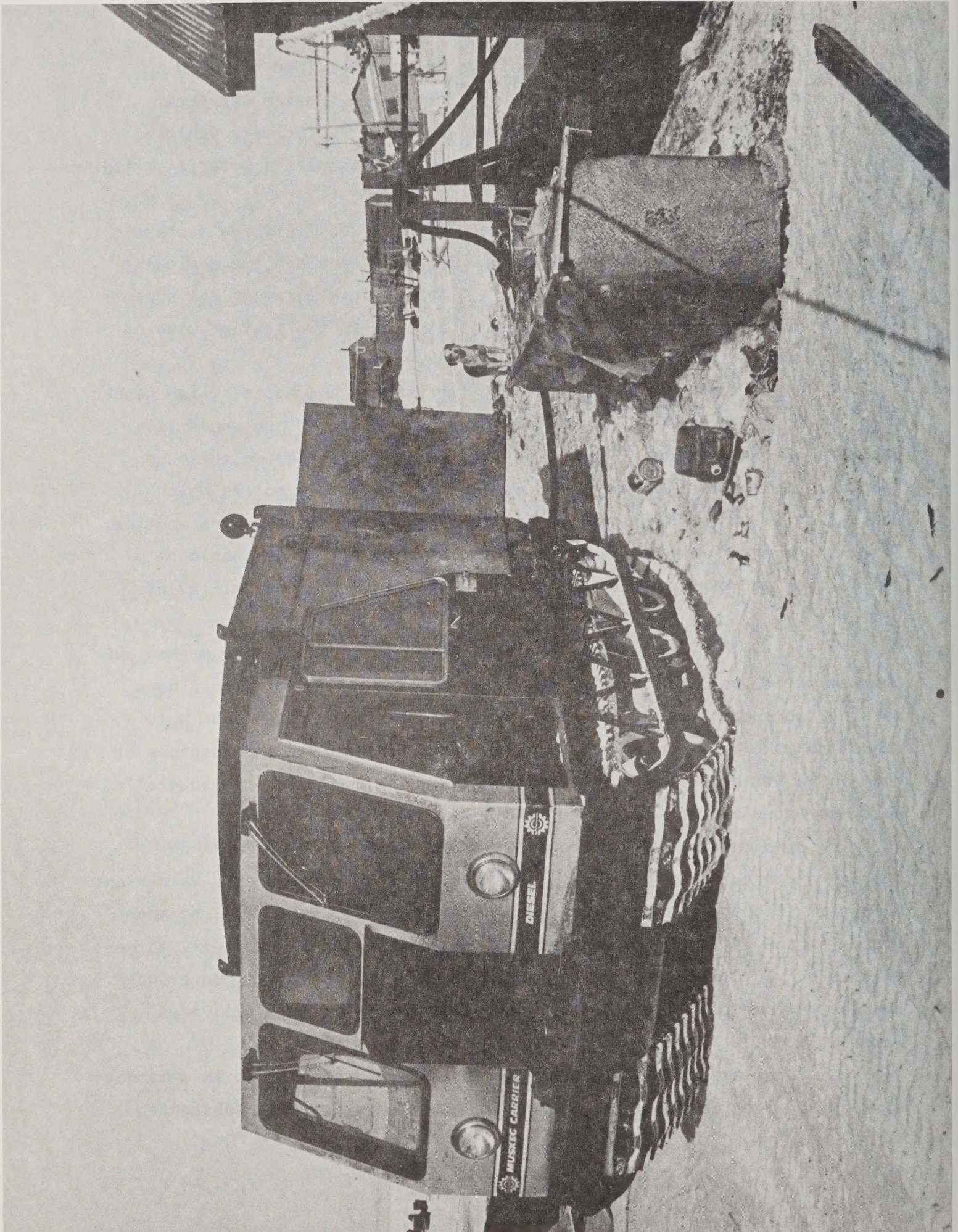


FIGURE 8. WATER DISTRIBUTION VEHICLE

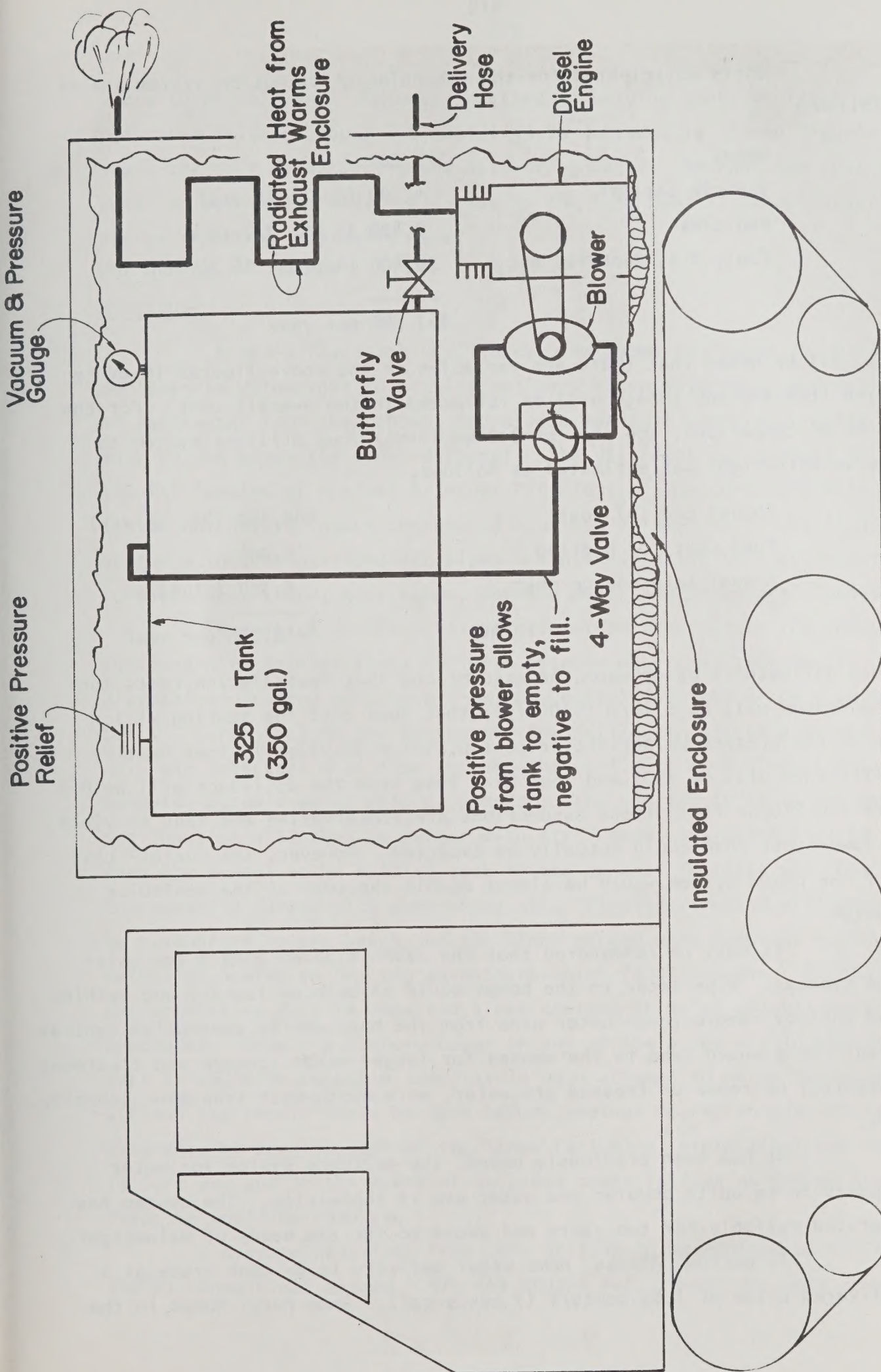


FIGURE 9. SCHEMATIC DIAGRAM OF DELIVERY VEHICLE

Costs anticipated for the vehicular distribution system are as follows:

Wages	\$18,700
Vehicle Shelter	4,700 (@ 8%, 25 yrs)
Vehicles	9,400 (@ 8%, 7 yrs)
Fuel, Oil, Repairs, etc.	28,400 (Approx. \$6.20/veh. hr)
	\$61,200 per year

It will be noted that there are variables in the above figures in every line item and any change will be reflected in the overall cost. For the sake of comparison, the cost of 3.2 km (2-mi) long utilidor system to serve Wainwright was estimated as follows:

Annual capital cost	\$98,900 (8%, 25 yrs)
Fuel cost for heating	6,000
Annual maintenance cost	5,300 (\$1.65/m)
TOTAL	\$110,200 per year

This estimate is based upon the assumptions that installation costs for the system will be \$328/m (\$100/ft), that fuel cost for heating will be at the present Wainwright price (\$0.24/l = \$0.93/gal), that heating efficiency will be 100% and that heat loss from the utiliduct will be 0.9 W/m (10 BTU/hr ft). These assumptions are conservative and tend to yield a lower cost than could actually be expected. However, the overall cost for the piped system would be almost double the cost of the vehicular system.

It must be remembered that the AVDP is based upon a low water use concept. Pipe water to the homes would allow home laundry and bathing and thereby remove these water uses from the more easily controlled central area. This would lead to the demand for larger water storage and treatment capacity, no reuse of treated graywater, more wastewater treatment capacity, etc.

As has been previously noted, the delivery system for water appears to be quite popular and water use is increasing. The system has operated reliably for two years and seems to fit the needs of Wainwright.

In Barrow, Alaska, home water delivery is by tank truck at a delivered price of 1.85 cents/l (7 cents/gal). Some rural homes in the

vicinity of Fairbanks use water carried to holding tanks by truck at a delivered price of about 1.0 cent/l (3.75 cents/gal). These figures reflect the cost of acquiring and delivering water. Perhaps the cost of water in Wainwright will again rise to the 1.59 cents/l (6 cents/gal) charge that was originally made.

UTILIDUCT

A small insulated "utiliduct," as shown in Figure 10, will be employed in Wainwright to provide delivery of potable water and collection of wastewater from the school, and as the means of carrying treated effluents to the beach for final disposal. The utiliduct is composed of 6.1 m (20 ft) lengths of nominal 6-inches PVC plastic pipe concentrically held inside nominal 12-inches corrugated aluminum culvert by foamed in place urethane insulation. Smaller pipes are placed inside this protective shell to carry heat trace, gray water, potable water and treated effluents.

Operation of the utiliduct is intermittent since the school is equipped with holding tanks for both potable water and gray water. Also disposal of treated effluents from the central facility is on a batch basis. Current plans are to operate the utiliduct in such a manner that only one substance will flow through the utiliduct at a given time. For example, potable water will be pumped to the storage tanks in the school and the line will then be purged with air. Next, graywater will be pumped from the school to be holding tank in the central facility and that line subsequently purged with compressed air. Finally, treated effluents will be discharged to the beach and the lines purged with compressed air. This method of operation has two advantages which favor its use. First, only one protective duct is required since contamination of potable water is precluded. Should a rupture occur in any of the pipes within the utiliduct it would be detected immediately upon attempt to purge the line with air and the repair could be made before another operation was initiated. Secondly, by purging each of the lines following intermittent use the line is left dry and in the event of extended power failure no damage due to freezing would be incurred.

Average heat loss from this utiliduct, maintained at 4.4°C (40°F), should not exceed 4 W/m (43 BTU/hr ft). Under the most severe

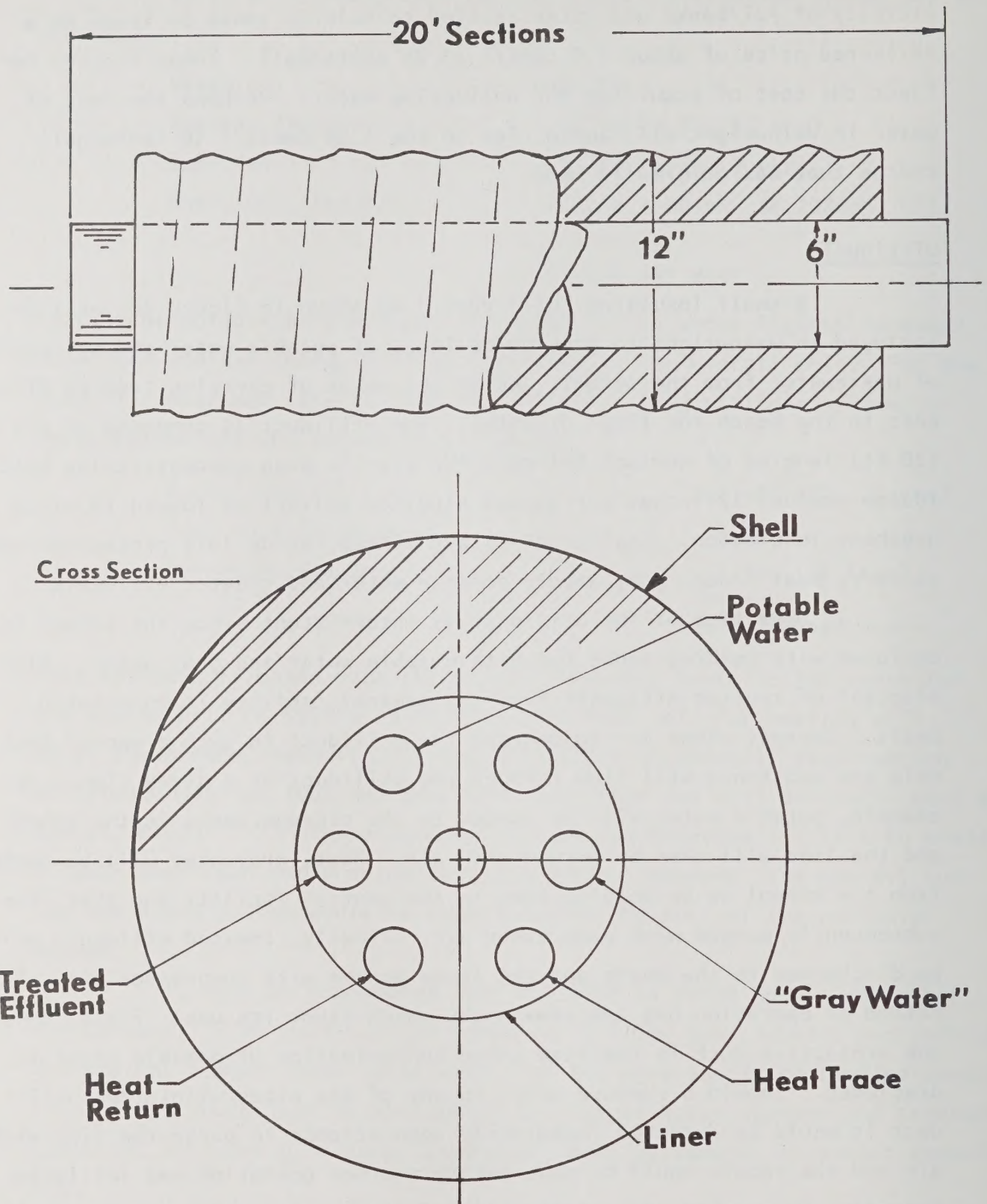


FIGURE 10. TYPICAL UTILIDUCT

temperature conditions expected in Wainwright, heat loss should not exceed 10 W/m (115 BTU/hr ft). Heating will be provided by a pair of lines carrying heated propylene-glycol-water solution. Heat will only be introduced into the utiliduct when the temperature in the duct is below 4.4°C (40°F). Some heating will be achieved by the movement of potable water and graywater through the utiliduct.

The heat requirement of this utiliduct will be met by "waste" heat recovered from the exhaust of the diesel-electric generator set. Actually, more heat will be salvaged from the generator's exhaust than will be required for utiliduct heating; hence, the surplus will be used in other processes within the central facility.

Purchase price of the utiliduct described, including the small carrier pipes housed within it, is approximately \$49/m (\$16/ft) f.o.b. the factory near Seattle, Washington. The installation cost is quite low since a crew of two or three men can easily install an average of 15 m (50 ft) per hour. Based on prevailing union wages, installation costs would be less than \$3/m (\$1/ft). This utiliduct is small and a similar system could not be expected to provide adequate service if used in a piped distribution system except for house connections.

Water lines between the raw water storage tank and the AVDP building are merely insulated pipes which are equipped with electrical heat trace for emergency use. The pipes are nominal 1-1/2 in. copper tube concentrically encased in approximately 10 cm (4 inches) of urethane insulation with an outer jacket of corrugated aluminum. In the event of extended power failure, valves have been provided which permit draining these service lines to prevent freeze damage.

SYSTEM RELIABILITY

Simply stated, Murphy's Law is "Anything that can go wrong will". This will cause many people to smile and think "not in my installation." Unfortunately, such people are naive. All equipment will eventually break down and in the case of a utility system this must be anticipated and included in design considerations.

Arctic climate and remote conditions will impose demands upon components and whole systems which designers in warm city offices regularly

overlook. An axiom which applies to this situation goes: "Service conditions as given on specifications will be exceeded." Believe it! Furthermore the axiom which states, "The best approximation of service conditions in the laboratory will not begin to meet those conditions encountered in actual service" becomes more and more applicable in direct proportion to the difficulty of access to the project.

Designers and managers must face the facts squarely and admit that the risk of failure of critical components is high. If this is done then the design will incorporate failsafe innovations so that when the critical component does fail there is a way of protecting the remaining components. But an experienced arctic practitioner will not even fully trust the failsafe services and will back them up with alternative or additional "escape" routes.

In the AVDP the most critical ingredient is electric power. Without it the project not only fails to perform its function but is in jeopardy of freezing or other calamity. Heat, fire protection and fuel supply are other critical components which demand thorough attention.

The AVDP incorporates a number of ideas which are intended to increase the reliability and safety of the system. Many of these provisions are required by the complexity of the system and further increase its cost. No enumeration of those provisions will be given here. These comments have been included to point out that any such system must account for reliability and safety if it is to be successful.

THE FUTURE

There are many ideas of what approach should be taken with future projects of this kind. Some people expound the virtues of the simple watering point while others are outspoken about the fully piped system. The politics and economics of utility systems is complex and beyond the comprehension of most people.

If systems are to be provided which require more than is offered by the watering point and yet are restricted by cost to something less than the fully piped system, the central village or neighborhood concept may be a solution. Improvements in the economics and dependability of central utilities will surely be made in the future.

System integration is a method which can be used to improve the economy of a central system. Except for labor, fuel is the single most expensive and critical ingredient required for operation of a utility system. Fuel economy can be realized by a thoughtful process interfacing in such a way that an energy cascade is developed. In this way significant increases in overall system efficiency can be achieved.

For example, electrical power generation by diesel engine is about 30% efficient. About 35% of energy input into a diesel engine is lost in exhaust heat and another 35% is lost in engine and oil cooling if conventional generators are used. By incorporating heat exchangers in the power generation subsystem, heat can be reclaimed for use in other processes such as water heat and space heat. To put a value on this approach, assume fuel is \$0.24/l (\$0.90/gal) and that the generator supplying power is a 250 kW unit with a fuel consumption of 75.7 l/hr (20 gal/hr). The electrical energy generated in one hour will be 250 kW hr (9×10^8 joules) and the chemical energy expended in the same time will be about 29.5×10^8 joules for an efficiency of about 31%. If a heat recovery silencer is installed which has an efficiency of 40% then 413 MJ ($0.4 \times 0.35 \times 29.5 \times 10^8$) of heat energy can be salvaged each hour from the exhaust. Now if a heat exchanger is installed in the engine cooling system with an efficiency of 50% additional heat recovery amounting to 516 MJ ($0.5 \times 0.35 \times 29.5 \times 10^8$) joules can be realized. Assuming that there is a use for the recovered heat energy, fuel use efficiency has suddenly increased to 62%. In other words, the system which uses the energy cascade has only half the fuel cost of the non-integrated system.

With a little imagination one can see how this same principle applies to lower level energy. Hot wastewater is hard to treat so a heat exchanger may provide both a means of salvaging heat and cooling the wastewater. Or, building exhaust air contains heat which is normally wasted but there are heat exchangers available which can extract some of the exhaust air heat and use it to preheat the incoming cold air.

Design and construction methods for facilities intended to serve communities in cold regions should be examined. There is potentially great benefit from the pre-fabricated modular approach to construction of utility facilities in remote areas. Costs may be reduced and reliability increased through the application of this concept.

One of the major deterrents to this approach at the present time is that facilities for pre-assembling and testing entire modules are non-existent. The present demand is apparently not great enough to warrant the initial investment required for production facilities.

Modularization can be viewed in at least two ways; first is on the subsystem level and, second is modular integrated systems. Subsystems comprising utility service include but are not limited to:

1. heating;
2. electric power;
3. potable water treatment and storage;
4. graywater treatment and storage; and,
5. blackwater treatment and storage.

The AVDP concept includes two additional subsystems:

1. laundry; and,
2. bathing.

Visualize a basic building block approach for providing utility services. Size can be defined for each of the subsystems for a given population to be served. For example:

Population = 100 persons

1.	Potable water treatment	= 15 kl/day (4000 gpd)
	Potable water storage	= 15 kl (4000 gal)
2.	Graywater treatment	= 15 kl/day (4000 gpd)
	Graywater storage	= 15 kl (4000 gal)
3.	Blackwater treatment	= 750 l/day (200 gpd)
	Blackwater storage	= 750 l (200 gal)
4.	Electric generating capacity	75 kW
5.	Heating requirement	
	(central buildings only)	290 kW (10 BTU/hr)
6.	Laundry	1 washing machine
		1 dryer
7.	Bathing	2 shower stalls

To serve a population of 350 it would be necessary only to install four of each of the subsystems. As the population grows, additional modular units of each subsystem could be added thus achieving a degree of reliabi-

lity not inherent in a single system. Each subsystem might be housed separately in a modular mobile building with sizes chosen so that adding additional units could be easily accomplished.

There is obviously some limitation to the single central community facility. In larger communities more than one facility would be desirable. The modular integrated utility system could meet this need. Neighborhood centers employing this system could be provided to conveniently serve either a large population or a population spread over relatively great distances.

Reliability of modular systems may be greater than field fabricated systems for several reasons. Controlled factory conditions of manufacture give greater assurance of adherence to specifications than a "bush" construction job. Testing prior to field installation is possible for factory-built modules, thereby eliminating some of the usual "shake-down" problems. In addition, skilled labor is more readily available in factory situations than in the bush.

Economic factors which favor the pre-built modular approach are much the same as those which imply greater reliability. One economic factor which detracts from this approach is the relatively large volume of the modules to be shipped to remote locations and the higher freight costs associated.

"Integration" is equally as important as "modular" in this discussion. Integration is important to both economics and safety but it increases the initial capital investment required.

It is not uncommon to waste large quantities of water or energy in utility operations. It is, however, unnecessary to waste either. If no attempt is made to reclaim useable byproducts, waste occurs; when salvage is attempted, only losses occur. Alter [4] points out that reclamation of water offers more promise in cold regions than in most other places. Energy salvage, likewise, offers greater benefits and is accomplished with higher efficiency in cold regions than in most other places.

Integrated utility systems should be developed to account for losses and should be engineered to minimize wastes. Planning and design should include as many factors of community life as possible so that the greatest benefit of subsystem integration may be achieved. Heating and

serving public buildings other than central utility buildings with electricity, water and sewerage should be investigated. If possible, housing, transportation and communication should be included in the system analysis. A wide variety of alternative approaches should be investigated and perhaps integrated into utility systems. There is no overriding logic to the employment of a single technique for accomplishing a given goal. For example, village sewerage may be best accomplished by integrating vacuum pressure and gravity sewers, or a water distribution system may best be accomplished by a combination of piped system and trucked delivery. If heat is a community-wide utility there is no justification for rates based upon transmission methods and the customer served by steam or hot water would expect to pay the same price per kW of heat as a customer in a more distant location who is required to heat electrically.

The concept of integrated utility systems is not new but it is undeveloped and much effort is needed to polish the analysis and design techniques if utility services are to take this logical form.

Realizing the full value of the integrated system approach in an older community may be more difficult than in a village or camp which is presently being planned or developed. This is true because of the layout and diversity of structures in the older community since most older communities have just grown without a plan. This does not mean that the use of integrated systems should not be attempted in the older communities but rather that the result of their use will be less dramatic.

Most native communities in Alaska are unable to develop their own utility systems and must rely upon outside capital, guidance and technology for a beginning and for operating support. The integrated system approach may offer economy in the operation of utility systems which will permit them to be supported entirely by the community they serve.

Life style of people in the remote communities of the north is in the process of change. The AVDP has gained acceptance by the people it serves just as the piped water system has been accepted in other parts of the world. Merely because a system is different is no reason to reject it.

As northern communities grow and outgrow the single central integrated utility system, additional units can be added in a modular

fashion to meet the needs. This may have the very desirable aspect of reliability which can stave off the catastrophe of failure when a single unit or component subsystem fails.

Space age technology is complex and expensive at the present time but this may change. This paper has presented the case for the AVDP at Wainwright which is a very active approach to utilities in the north. Perhaps a future development will show the means and methods for a passive approach which will provide the same utilities at less expense in manpower and dollars and in greater harmony with the northern environment. The concern for utilities in the north is relatively new and there is much room for improvement in the existing systems regardless of the approach.

REFERENCES

1. Reid, Barry H., "Alaska Village Demonstration Projects: First Generation of Integrated Utilities for Remote Communities", Proceedings of Symposium on Wastewater Treatment in Cold Climates, EPS 3-WP-74-3 (March 1974).
2. Bailey, James R., et al., "A Study of Flow Reduction and Treatment of Wastewater from Households", Report 11050 FKE, Federal Water Quality Administration (December 1969).
3. Puchtler, Bertold, "Social and Economic Implications of the Alaska Village Demonstration Project", Working Paper No. 20, Arctic Environmental Research Laboratory (October 1973).
4. Alter, Amos J., "Sewerage and Sewage Disposal in Cold Regions", Cold Regions Science and Engineering Monograph 11-C5b, U.S. Army, Corps of Engineers (October 1969).
5. CH₂M-Hill, Consulting Engineers, Plans and Specifications (1974).

APPENDIX - DESIGN REQUIREMENTS

Building Foundations

1. A platform shall be designed for placement on piling foundation to support the building and its equipment, tanks and personnel. Tanks

may offer the heaviest loadings which could exceed 3.9 Mg/m^2 (800 lb/sq ft). The base platform shall be elevated not less than 0.9 m (3 ft) above the ground to permit adequate ventilation and prevent thawing the permafrost.

Concrete may be employed as a platform surface, but specification of this material should occur only after the economics of its use under remote cold climate conditions have been examined.

Design may employ two stories for all or part of the building in order to allow for placement of gravity drains and other fixtures. Dead spaces and spaces to which only difficult access is possible shall be avoided. There shall be no penetration of the base platform.

2. The foundation of the structure shall be shielded in such a manner (as by fencing) to prohibit access to the area beneath the building. The barrier shall allow proper ventilation of the foundation and shall be non-combustible material.

Architectural

1. A building of approximately 280 m^2 (3,000 sq ft) shall be designed to contain all functions of the AVDP with the exception of vehicle shelter and power generation. The layout of space within the building shall provide adequate room for equipment maintenance and personal safety. Space may be divided into two approximately equal parts for public occupancy and for process equipment.

2. The structure shall have characteristics which allow for economical shipment, erection, finishing and maintenance under remote arctic conditions. Corps of Engineers design criteria for wind and snow loading shall be used. Primary structural members shall be steel, joined by bolts. Sheathing shall be metal and shall have weather resistance either by painting or galvanizing. There shall not be any continuous metal connection between exterior surfaces and interior surfaces. Insulation shall be provided so that overall "U" factors for surfaces will be: walls 0.09 (0.05), floor 0.05 (0.3), and roof 0.05 (0.03), in which "U" is expressed as $\text{W/m}^2 - ^\circ\text{C}$ ($\text{BTU/hr/}^\circ\text{F/ft}^2$). Urethane insulation is not recommended. Vapor barriers shall be placed in such a manner to prevent moisture transmission into the insulation and held in position to avoid future damage. The sheathing of the roof shall be ventilated to expose

a cold surface and avoid "glaciating". A configuration will be selected which permits optimum use of the entire volume enclosed. The volume of the building should not exceed 1450 m^3 (51,000 cu ft) gross.

3. Interior partitioning shall be made in manner which provides resistance to fire. Hardware and other finish materials shall be selected to withstand hard use by the public.

4. Entryway.

a. The main doorway of the building shall be above ground level so as not to be blocked by drifted snow.

b. Passageway into the laundry shall be adequate for safe and uncrowded entrance and egress.

5. Laundry.

a. The laundry area shall contain four washer-extractors and five dryers of heavy-duty design. Water for washing machines will be treated wastewater from the showers and shall be entirely separated from the potable water system. Dryers shall be heated by the central heating system of the AVDP.

b. In addition to machinery described above, the laundry shall contain tables for sorting and folding clothes, seating for patrons, one drinking fountain and coat hangers for outer garments.

6. Shower Room/Toilet.

a. Four shower stalls shall be provided in each shower room. Fixtures shall include devices for flow rate limitation to 5.7 l/min (1-1/2 gal/min) and temperature control to prevent accidental scalding. In addition, flow shall be controlled by coin box timer adjustable with a two to ten-minute range.

b. Two toilets shall be provided in each shower room. The fixtures shall be low water use compatible with the non-water-carried waste concept of the project.

c. Two lavatories shall be provided in each shower room. Fixtures shall be flow-regulated to allow a minimum water flow.

d. Each shower room shall incorporate sauna bath not to exceed 5.6 m^2 (60 sq ft) in area. Equipment for heating the sauna shall be capable of reaching and maintaining a maximum temperature of

93°C (200°F). A floor drain shall be provided in each sauna to permit drainage of excess water used and water used for janitorial purposes.

e. Additional fixtures shall be provided in each shower room to allow for orderly occupancy such as coat hooks, towel bars, benches, etc.

7. Office

An area not to exceed 9.3 m² (100 sq ft) shall be provided to serve as an office for the facility manager. A "dutch door" opening to the laundry will allow this space to double as a laundry attendant's station.

8. Process Equipment Area

Ample space shall be provided for the operation, maintenance, and repair of the equipment for the following processes:

a. Potable Water

Water for the city of Wainwright is taken annually from a shallow lake about 2750 m (9,000 ft) southwest of the city and stored in an insulated and heated 3.8 Ml (1,000,000 gal) storage tank. Water may not be withdrawn from the lake after freeze-up. Raw water is of good quality with the following characteristics which are not subject to significant change:

pH	7 to 7.2 pH units
Hardness	80 mg/l as CaCO ₃
Turbidity	5 JTU
Color	4 PCU
Suspended solids	5 mg/l
Total solids	250 mg/l
Temperature	4.5-10°C (40-50°F)
Coliform bacteria	0 per 100 ml

Treatment of raw water may best be accomplished by filtration, carbon absorption and disinfection. Daily use of water in the city (and facility) must not exceed 18.9 kl (5,000 gal). Equipment shall be sized to permit treatment of daily requirements in a 10-hour cycle.

Raw water is to be circulated from the storage tank to the AVDP facility to provide heating necessary to prevent freezing. A

raw water storage tank not larger than 5.7 kl (1,500 gal) may be included in the design. This tank shall incorporate heaters as required to transfer approximately 44 kW (150,000 BTU/hr) under the most severe conditions.

Potable water distribution shall include pumping and piping necessary for distribution of potable water to showers, sinks, and drinking fountains in the central facility and connection to the potable water delivery pipe in the utiliduct to the school. Pressure for distribution will be generated by a pump in combination with a captive air cell. System design should allow pressure to remain above 20 psi (14 Mg/m²) at all fixtures.

Also, potable water shall be available from a conveniently located, metered outlet for sale to the public at the plant into hand and sled-carried containers.

A potable water stub shall be provided for the line to the vehicle shelter for rapid loading of tank vehicles.

b. Graywater.

Graywater is wastewater originating from laundry, showers, potable water filter backwash, and sinks in the central facility, the school and homes (returned by vehicle). Collection of graywater shall include provision for attachment to the utiliduct and shall be maintained separate from piping carrying human wastes (blackwater). Graywater will be pumped to the AVDP from the school through the existing utiliduct. Graywater from homes will be pumped to the AVDP from the PHS vehicle garage. Lines will be purged with compressed air and maintained dry when not in service.

Storage of graywater shall be designed to contain not less than one day's production of potable water. Small storage capacity in connection with the laundry facility leads to treatment problems arising from both rapidly varying wastewater chemical characteristics and temperature.

Graywater treatment must be of highest caliber and may be of physical/chemical or of biological/physical/chemical type. Product shall be of a quality to permit reuse in the laundry. Influent graywater may be expected to have the following range of characteristics:

pH	7-8 pH units
Color	20-50 PCU
Turbidity	200-300 JTU
COD	500-1500 mg/l
Suspended solids	400-900 mg/l
Total Solids	1600-2400 mg/l
Total vol. solids	500-800 mg/l
Vol. suspended solids	200-500 mg/l
NH (as N)	2-10 mg/l
Nitrate (as N)	0.1 - 0.5 mg/l
Total Phosphate (as P)	5-30 mg/l
Temperature	21-43°C (70-110°F)
Coliforms	10 ⁶ /100 ml

c. Recycle Water Storage.

Storage shall be provided for treated graywater. The volume of storage shall be adequate to supply 100% of laundry demands for three hours. Water in excess of the basic storage capacity shall be discharged on a batch basis through the existing utiliduct to the beach.

d. Recycle Water Distribution.

Recycle water shall be distributed to laundry machines only. Connections to the treated graywater system for any other purpose shall be avoided. Recycle water piping shall be clearly marked. Pressure for recycle water distribution shall be generated by a pump in combination with a captive air cell. System design shall allow pressure to remain above 20 psi (14 Mg/m²) at all fixtures.

e. Blackwater.

Human wastes, urine, feces, and process sludge constitute blackwater and originate from toilets at AVDP, home honey buckets, and chemical toilets at the school. Blackwater from the school is conveyed by pressure through the utiliduct. The line will be purged with compressed air following batch transfer and remains dry when not in service. Storage capacity at the school is about 1.1 kl (300 gal), but will be transferred in batches probably half that quantity. Blackwater will be collected from homes by tank vehicle and transferred to the AVDP from the vehicle shelter. The village at large may contribute as much as 1.3 kl (350 gal) of blackwater per day based on 19 l (5 gal) per household per day.

Blackwater treatment shall be accomplished by separation of solids with batch treatment of liquid supernatant. Treated supernatant shall be discharged with excess treated graywater.

f. Solid Waste.

Compaction of materials for later landfill shall be provided. Reduction of travel to the city disposal site some five miles distant will be realized in this manner yielding better economy. Storage space for solid wastes prior to compaction shall be provided. The system shall be designed for 680 kg (1500 lb/day).

9. Water Testing Area.

An area shall be set aside for testing and process monitoring. This area shall allow for routine test performance and storage of test apparatus and supplies.

Remote reading water meters shall transmit signal to readout devices located in this area. Such meters shall be placed in the following locations and their remote readers approximately labeled:

- a. Raw water supply to potable water treatment.
- b. Potable water supply to storage tank.
- c. Potable water to delivery truck
- d. Potable water to school.
- e. Potable water to water heater.
- f. Potable water to in-building use.
- g. Recycle water to storage tank
- h. Recycle water to beach discharge
- i. Recycle water to water heater.

Alarms to indicate process malfunctions shall be placed in the water testing area. Alarms shall indicate high water in the gray-water storage tank, flame failure in building heating system, and low liquid level in the building heating system.

10. Shop Area.

An area for use as a maintenance shop for equipment shall be approximately 18.5 m^2 (200 sq ft) and shall be provided with a service entrance. A bench and a lockable tool cabinet shall be provided.

11. Storage Area.

Space shall be designed for storage of process chemicals, supplies, and spare parts. This space need not be contiguous and may make use of otherwise unoccupied space. Such areas shall, however, be lighted and otherwise provide for safe access and materials storage.

Mechanical

1. Heating System

a. This is perhaps the most complex subsystem in the AVDP because of the energy conservation concept. In this initial phase, the heat shall be provided by an oil-fired heater. At a future time, heat will be supplied as a by-product from the adjacent power plant.

Heat is required for the following functions and shall be supplied by the central heater:

- (1) Building heat.
- (2) Utiliduct heat.
- (3) Potable water heater.
- (4) Recycle water heater.
- (5) Sauna Bath (two).
- (6) Clothes dryer (five).
- (7) Water storage tank protection.
- (8) Vehicle shelter heat.

b. The heating system shall be composed of a liquid phase heater and an organic heat transfer fluid circulated through appropriate piping. The system must be capable of transferring 176 kW (600,000 BTU/hr). All pipes of 2 inches nominal diameter and less shall be gas welded except where unions or final connection with threaded couplings is appropriate. Larger diameter pipes may be jointed by arc welding. The system shall be fabricated, isolated, and pressure tested prior to introducing heat transfer fluid. Any leaks, thus discovered, shall be repaired by re-welding or tightening unions. Fuel meters shall be provided for each piece of fuel burning equipment.

c. Recovery of waste heat from the 40 kW generator set shall be considered. Findings will be discussed with the project engineer prior to proceeding with full design of this function. The existing 40 kW generator is a Detroit Diesel, Model 4045N, Unit 4A-148930.

2. Water Heaters

Water heaters shall be of an appropriate size and recovery rate to permit the central complex (laundry and showers) to operate with hot water for a 1-1/2 hr period at 100% use. Double jacketing between potable water and heating fluid is necessary to prevent contamination of water in the event of leakage.

3. Utiliduct Heat

Heat trace for the utiliduct to the school shall be by means of propylene glycol and water constantly circulated through 1-inch diameter plastic pipes. A duct temperature of 4.4°C (40°F) shall be maintained. Maximum fluid temperature within the utiliduct to the school shall not exceed 25.7°C (80°F)

4. Water Storage Tank

A year-round supply of fresh water is not available and a supply adequate for minimal needs must be stored for use throughout the winter. A one-million-gallon insulated storage tank was provided by the U.S. Public Health Service to fill this need. Water in the storage tank must be heated in order to prevent formation of thick ice layers which could damage the tank.

Protection for this storage tank shall be provided by heating raw water inside the AVDP facility and circulating it to the storage tank. Heat transfer at a maximum rate of about 43.9 kW (150,000 BTU/hr) will be adequate for this purpose. Control shall be provided so that heat flowing to the water storage tank can be regulated without waste.

5. Vehicle Shelter Heat

Heating the vehicle shelter shall be considered as a part of this contract. The shelter will be 9.75 m (32 ft) wide, 10.36 m (34 ft) long, and have approximately 3.66 m (12 ft) overhead clearance. Walls will be insulated to $U = 0.09$ (0.5), floor and roof will be insulated to $U = 0.05$ (0.03), where $U = \text{W/m}^2/^{\circ}\text{C}$ (BTU/hr/ $^{\circ}\text{F}$ /sq ft). Temperature of 21°C (70°F) shall be obtainable with the heating units provided.

6. Compressed Air

This will be required at several locations in the facility. Compressed air shall be piped to the utiliduct entrance so that lines to

the school and the garage building may be purged.

The shop area will require compressed air for tire inflation, lubrication equipment, paint sprayers, etc. Compressed air piping shall be stubbed to the future location of the power plant and the vehicle shelter.

Intake air for the compressor shall be taken from a location outside the building. Previous experience has shown that moisture-laden air inside the building leads to production of compressed air unsuited for many applications. Threaded pipe joints in the system shall be lubricated with a Teflon tape since most "goop-type" lubricants creep into air pressure regulators and other equipment.

7. General

Plumbing and tanks shall be designed to allow for simple and rapid draining to prevent damage by freezing in the event of an extended power failure.

Electrical

1. Initially, electric power for the AVDP will be provided by a 49 kW Detroit Diesel engine generator (single-phase, 110-200 V) located adjacent to the AVDP structure. Standby power will be provided from the city power system. City power is also single phase. In the future, a larger power generator may be provided adjacent to the AVDP to serve the entire electrical demand of the city.

2. The minimum acceptable levels of illumination shall be:

<u>Area</u>	<u>Lux</u>	<u>(Footcandles)</u>
Entryway	110	(10)
Laundry area	650	(60)
Shower room/toilet	320	(30)
Office	1100	(100)
Process equipment area	650	(60)
Water testing area	1100	(100)
Shop	1100	(100)
Storage	320	(30)

Control of lighting in the public use area of the complex shall be located in the office area to preclude tampering by uninstructed

individuals. Battery powered emergency lighting shall be provided to allow safe egress in the event of power failure. Exits are to be clearly marked.

Lighting in the process area shall be controlled by switches in each functional area. Emergency lighting shall be provided in the process area to permit safe movement and/or exit in the event of power failure.

3. Process controls shall basically be independent. Master control panels for each unit process shall be provided in each process functional area. Interface between processes shall be required as follows:

a. Potable water, treated graywater, and all backwash must be "locked out" when the graywater storage tank is full. That is, when the graywater storage tank is full, all of the following functions should cease automatically; intra-plant potable water distribution; re-cycle water distribution; washing machine operation; and process backwash.

b. When a fire is detected in the complex, power to all equipment except to fire pumps should be interrupted.

Watt-hour meters shall be provided for each process. In addition, a meter to measure the power supplied to the entire complex shall be provided.

Electrical design and installation shall be in accordance with the latest National Electrical Code and OSHA requirements.

Fire Protection Safety and Alarm System

1. The facility shall be designed with personnel safety and fire protection as a key consideration. National Building Code and OSHA Standards shall be observed.

A fire suppression system shall be designed to serve the entire facility. Water supply for the system will be the existing million-gallon storage tank. A 2-in. diameter galvanized steel pipe supplies water to the building from the tank.

2. Alarms shall be provided inside the building as appropriate to indicate fire. In addition, an outside alarm capable of being heard for one mile shall be provided. The outside alarm shall be designed to sound under the following conditions:

- a. Power failure.
- b. Fire.
- c. Temperature in the building is below 0.6°C (33°F).

VILLAGE SAFE WATER PROJECTS
IN ALASKA - CASE STUDIES

by

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DEFINITION OF PROGRAM

History

In Alaska there exists the traditional differentiation between urban and rural areas. Urban areas are the major municipalities such as Anchorage, Fairbanks, Juneau and Seward. Rural Alaska is called the "bush", and includes all of the State that is not urban.

Providing sanitation services (primarily water supply and waste disposal) in the urban areas is quite a different proposition than providing such services in the bush. In the past, State and Federal assistance to urban areas for water and sewer services has been provided through programs separate from programs assisting rural areas with obtaining sanitation services.

Municipal water and sewer grants

Communities in Alaska can receive financial assistance for installing water supply and waste disposal systems through the State Water and Sewer Municipal Grants program. Through this program both Federal and State funds are available for municipal sewage treatment and disposal, interceptor sewers, sewage collection and water supply. Communities receiving these funds are requested to provide matching funds in varying proportions, and that is the feature of the Municipal Grants program which has so far limited its impact in rural Alaska.

Bush programs

Until 1970, the only active program for providing sanitation services in rural Alaska was the U.S. Public Health Service, Indian Health Service, Office of Environmental Health. A description of that program is provided elsewhere in this symposium. In 1969 Senators Ted Kennedy and Ted Stevens toured rural Alaska and were appalled at the lack of sani-

tation services in bush villages. Their reaction was to promote a combination of a new Federal and a new State program to answer the need for rural sanitation services.

The Federal program was the Alaska Village Demonstration Project (AVDP), a description of which is provided elsewhere in this Symposium. The State program was the Village Safe Water (VSW) program. Simply stated AVDP was to construct about two projects demonstrating how best to supply rural sanitation services, and then the State was to follow along building sanitation systems as developed by AVDP.

The Village Safe Water Act

The Village Safe Water Act of 1970 was passed for the purpose of providing "safe water and hygienic sewage disposal facilities in villages in the State," and "to assure that there will be at least one facility for safe water and hygienic sewage disposal in each village." The Act stipulates that each facility will provide at least a safe water supply, means for sewage disposal, and bathing and laundry services. A village is defined as "an unincorporated community which has between 25 and 600 people residing within a two-mile radius; or a second class city." The VSW act is administered by the Alaska Department of Environmental Conservation (ADEC).

A village receiving a VSW project is not required to contribute toward costs of construction. The State may "provide for construction by contract or through grants to public agencies or private nonprofit organizations, or otherwise."

When a VSW facility is completed the recipient village must be given title to it. The village must agree to accept ownership of the facility and be responsible for its operation and maintenance. The State may assist a village with operation and maintenance expenses when the local governing body lacks sufficient financial resources.

VSW CONSTRUCTION EXPERIENCES

Description of projects

By the end of fiscal year 1977, Village Safe Water Sanitation facilities will have been constructed in nine Alaskan villages. Table 1 is a listing of the nine villages along with data concerning population, location and climate.

The VSW projects in all nine of the villages listed in Table I will consist of constructing central sanitation facilities. A central facility is a building from which the various sanitation services are dispensed (e.g. a faucet for filling a water bucket or barrel, a dumping bin for "honey buckets", clothes washers and dryers, showers, and rest rooms). The central facility concept is in contrast with water and sewer services to individual homes through piped distribution and collection systems. In some communities, factors such as permafrost conditions, climate and community layout might make a central facility preferable to distribution and collection systems.

TABLE I. VILLAGE RECEIVING VSW FACILITIES

Village	Location in				Population	Mean Jan. Temp. °F	Mean Annual Temp. °F
	N. Lat.	W. Long.					
Northway	62 58'	141 56'		40		-24	+22
Chevak	61 32'	165 35'		447		+2	+29
Nulato	64 43'	158 06'		330		-16	+25
Selawik	66 36'	160 00'		521		-16	+22
Alakanuk	62 41'	164 34'		512		-3	+28
Pitkas point	62 02'	163 17'		85		-3	+28
Koyukuk	64 53'	157 42'		124		-16	+25
Beaver	66 22'	147 24'		101		-20	+30
Kongiganak	59 52'	163 02'		200		+2	+30

Northway and Chevak

In late 1972 and early 1973 the villages of Northway and Chevak requested assistance under the VSW program in finishing central facilities they had begun to construct on their own initiative. Since Northway and Chevak had committed their own resources and thus demonstrated a sincere desire to improve sanitation in the villages, they were granted VSW assistance.

Before the VSW project began, Northway had a one-story wood frame building of about 700 square feet situated over a well. The building

housed a one-room health clinic, a watering point for the village and a room for community gatherings. The VSW project consisted of improving the watering point, and adding laundry equipment and showers. Wastewater from the facility (containing no toilet waste) is discharged to a small natural pond. Chemical toilets used in the facility are emptied into a Federal Aviation Administration sewage treatment facility several miles away.

Nulato, Selawik and Alakanuk

In early 1973 the Alaska Department of Education, lacking funds to provide water and sewer services for new schools scheduled for construction in Nulato, Selawik and Alakanuk, asked ADEC to install VSW facilities in those villages. The VSW facilities were to provide sanitation services for both the new schools and the villages. ADEC agreed to this arrangement in return for promised operation and maintenance support from the schools.

In each village the school and VSW facility were designed and constructed under joint contracts administered by the Alaska Department of Public Works. All three VSW facilities were patterned after the AVDP projects in Emmonak and Wainwright. They are two story structures approximately 55 feet square, and built on piles. The facilities contain washers and dryers, showers, saunas, rest rooms, solid waste disposal bins, honey bucket dumps and a watering point.

Nulato. At Nulato the water source is a well, water from which contains more than 28 mg/l iron and 5 mg/l manganese. Water treatment is pre-chlorination followed by alum and lime coagulation - flocculation, rapid sand filtration, and post-chlorination. The water treatment plant is a standard Met-Pro physical/chemical package plant with 14,000 gpd capacity.

The sewage treatment plant is also a 14,000 gpd Met-Pro physical/chemical package plant, in which the unit processes are alum and lime coagulation/flocculation, carbon sorption, rapid sand filtration, and chlorination. Treated effluent is discharged to the land surface through an elevated, insulated and heated conduit.

Sludge from both the water and sewage treatment plants is dewatered by centrifugation and then incinerated. Solid waste from the solid waste collection bin is also incinerated.

Neither one of the treatment plants has performed consistently well since the facility was completed in November of 1974. Sludge build-up has been a problem in both plants, treated water frequently contains iron and manganese in excess of 1 mg/l in spite of massive chemical dosages, and solids accumulation in the sewage treatment system has severely reduced plant capacity.

The primary source of building heat and heat for the dryers is a heat exchanger on the incinerator stack. A hot water boiler is the secondary heat source, and a hot air furnace is the "last ditch" source of building heat in case the incinerator and boiler fail or are inadequate. The incinerator, boiler and hot air furnace are interconnected through a complex control system which has been very difficult to keep operating properly.

Selawik and Alakanuk. The water and sewage treatment plants at Selawik and Alakanuk are the same as the plants at Nulato -- Met-Pro physical/chemical package plants with 14,000 gpd capacity. For these villages, however, the water is obtained from surface sources, and product water has been of good quality since the facilities were completed (Selawik in October, 1975, and Alakanuk in December, 1975). The sewage treatment plants also seem to be operating well, although data on effluent quality are not yet available. Treated effluent is discharged to the land surface.

The floor plans, mechanical systems, and methods of providing sanitation services in the Selawik and Alakanuk facilities are very nearly the same as in the Nulato facility.

Pitkas Point, Koyukuk and Beaver

The Pitkas Point VSW facility was completed in February, 1976. It is a wood frame structure of about 1300 square feet resting on a post and pad foundation and containing a watering point, honey bucket dump, washers and dryers, rest rooms, showers and saunas. The water source is a collection gallery in the bed of a creek. Water treatment is rapid sand filtration and carbon sorption on an as needed basis, followed by chlorination and fluoridation. Sewage is treated in a secondary biological system which consists of four 1000 gpd extended aeration package plants interconnected through a splitter box. The package plants are Multi-Flo

units which consist of an aeration chamber, and solids separation through a filter membrane. Treated effluent is discharged to an underground leach field. The Pitkas Point school will be plumbed into the VSW facility to receive water supply and sewage disposal services.

Design of the Koyukuk VSW facility was completed in February, 1976, and the well intended for its water source was drilled in September of 1975. This facility will be similar in size and configuration to the one in Pitkas Point except that it will contain no saunas and will have a pile foundation system. The low capacity well (6 gpm) produces good quality water, so water treatment will probably be only chlorination and fluoridation. Treated sewage effluent from three 1500 gpd (Multi-Flow plants will be discharged into a stream channel which has intermittent flow. The new school to be constructed in Koyukuk next year will receive water supply and waste disposal services from the VSW facility.

The Beaver project is in the design phase. This facility will provide the same services as the one in Pitkas Point, including service for the village school. The water source will be two wells in the thaw bulb of the Yukon River. Water treatment will depend on the quality of water obtained from the wells. Sewage treatment will be extended aeration in a 5000 gpd Bio-Pure package plant. Treated effluent will be discharged to a sub-surface leach field in the thaw bulb of the Yukon.

Kongiganak

The Kongiganak project is just entering the design phase. The facility will be basically similar to the ones in Pitkas Point, Koyukuk, and Beaver; and it will serve the village school. Water supply will be a very difficult proposition in Kongiganak, with desalination a distinct possibility (or necessity).

An interesting aspect of the Kongiganak project is that a wind-mill may be installed to generate electric power.

COSTS

Table 2 is a summary of capital construction costs for VSW projects to date. The costs shown include both design and construction. The figures for Koyukuk, Beaver and Kongiganak are preliminary estimates.

TABLE 2. CAPITAL CONSTRUCTION COSTS FOR VSW PROJECTS

Villages	Cost (in thousands of dollars)	
Northway	60	
Chevak	75	VSW contribution
Nulato	860	
Selawik	1100	
Alakanuk	1000	
Pitkas Point	350	
Koyukuk	440	
Beaver	450	
Kongiganak	550	

OPERATION AND MAINTENANCE

Construction of any utility system, especially in the relatively harsh environment of rural Alaska, is money wasted unless provisions are made for the system to be properly operated and maintained. Most, if not all, villages lack the necessary resources to administer, manage, operate and maintain even a minimum VSW facility (or any other utility system for that matter) without continuing outside assistance.

A facility to provide the services specified by the Village Safe Water Act must contain relatively sophisticated equipment and appliances. Since public health is at stake, water and water treatment systems must be kept operating properly at all times. Hence at least one full-time trained and paid maintenance man must attend every VSW facility.

Virtually all of the maintenance people have to come from the villages where VSW plants are installed because "outsiders" are usually reluctant to take up residence in remote villages. Since people with the training and experience necessary to operate and maintain a VSW facility are usually not available locally, an elaborate, extensive and continuing program for training of plant operators is required.

A continuous and generous flow of revenue is required to meet the operation and maintenance expenses of VSW facilities. In addition to

the plant operator(s) salary, there are treatment chemicals, electricity, fuel, and replacement parts to buy.

In Table 3 are listed the estimated annual operating budgets for VSW facilities completed as of February, 1976. The figures in Table 3 exclude amortization of capital costs.

TABLE 3. OPERATING BUDGETS FOR VSW FACILITIES

Villages	Annual Operating Budget (thousands of dollars)
Northway	28.0
Chevak	37.5
Nulato	109.0
Selawik	109.0
Alakanuk	109.0
Pitkas Point	46.0

Sources of revenue in the villages are limited. Individuals who use the VSW facilities will pay fees, but fees cannot be so high people no longer can afford to use the facilities. Two to five thousand dollars per month might be raised through users' fees in larger villages (400 to 500 residents) and proportionately less in smaller towns. Public Health clinics, some owned by the U.S. Public Health Service and some owned by the villages, might receive water supply and waste disposal services from VSW facilities and thus become sources of revenue, but not more than a few hundred dollars per month. Fees paid for school water and sewer services represent a third source of revenue which could routinely amount to about 25 percent of the VSW facility operating budget. Hence as a general rule, more than half of the money needed to operate VSW facilities will have to come from outside the villages.

CONCLUSION

The Village Safe Water program grew out of recognition of the critical need for adequate sanitation services in rural Alaska. Providing

such services involves two major efforts: 1) capital construction, and 2) operation and maintenance. Of the two activities, operation and maintenance has proved to be the most difficult in the VSW program.

The technological problems associated with providing water supply and waste disposal services in the arctic are indeed unique and challenging. But by far less tractable are long term operation and maintenance problems such as finding enough money to pay the bills, keeping mechanical equipment operating at remote sites, and managing personnel from great distances without dependable communications.

Without dependable provisions for operation and maintenance of sanitation facilities in rural Alaska, capital construction of such facilities is wasted effort.

FIELD PERFORMANCE OF A SUBARCTIC UTILIDOR

by

Sherwood C. Reed

U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New HampshireINTRODUCTION

The connecting utility systems are often the most critical and costly element for northern communities. The basic need to transmit water and sewage becomes the controlling factor in community planning and development and often dictates the configuration and distribution of structures and the life style of the occupants.

A considerable research effort has, and is, being expended to develop more cost effective systems and to find alternatives to conventional piping systems.

A conventional approach with pipe systems in the arctic is to nest all the utilities in a single conduit commonly termed a utilidor. Choice of materials and construction techniques and the decision to place the system above ground, at a shallow depth or deep burial are based on a careful evaluation of specific site conditions.

This paper will describe the design, construction, performance and ultimate failure of a functioning utilidor. It is hoped that the lessons learned in this case study description will be of interest and use to engineers concerned with planning and design of such systems.

LOCATION

The facilities of concern were located at the USACRREL Alaska Field Station on Farmer's Loop Road in Fairbanks, Alaska. Pertinent meteorological data for this location are: Mean annual temperature -3.06°C (26.5°F), design air freezing index 6619°F degree days, mean annual snowfall 155.2 cm (61.1 inches) per year, average of 193 days per year with below freezing average temperature, recorded low temperature -54.4°C (-66°F), design low temperature (sustained) -51.1°C (-60°F). The site is underlain by permafrost to depths of approximately 85.3 m (280 ft) with a 1.2 - 1.5 m (4-5 ft) active layer at the surface. Soil types are primarily silts and

silty sands with high moisture contents and some organic materials. It is a warm permafrost, with in situ temperatures averaging -1.7°C (29°F), and if thawed would provide little or no structural support for imposed loads.

General lay-out of the site is illustrated on Figure 1. Only those buildings served by the utilidor are shown. The water supply was located at the eastern end and the waste treatment system at the southern extremity. Functional use of the buildings included laboratory and offices, a single family dwelling and the station administrative office. Station population during this period was 12-14 persons. This included two full-time occupants of the residence with the remaining being day workers. During the period discussed in this paper potable water was truck delivered to a storage tank in the water supply building.

The Station has been at this location since 1944. Water service has followed the pattern described above since 1948. Sewage flow, prior to construction of the treatment plant, proceeded from the office in a westerly direction to a timber crib septic tank near the present outfall. Both water and sewerage services were enclosed in a simple wooden box utilidor with glass fiber insulation and electrical heat tapes for thermal protection. Problems were frequent and of the type common to northern communities. Power outages or heat tape failures rapidly resulted in freeze-ups and loss of service. The addition of sufficient heat in the utilidor to prevent freezing then resulted in complaints about high water temperatures at the cold water taps in the buildings. It became necessary to install small holding tanks in each building to allow the water to cool down to a desirable temperature. The thermal integrity of the glass fiber insulation was lost whenever it became wet.

In 1965, it was decided to replace the original system after 17 years of service. Concept development, design and construction of the new system were the responsibility of the U.S. Army Corps of Engineers, Alaska District. USACRREL designed the supporting foundations, provided for monitoring instrumentation in the utilidor, and requested that the final segment of the system be a different configuration and construction to permit comparative studies.

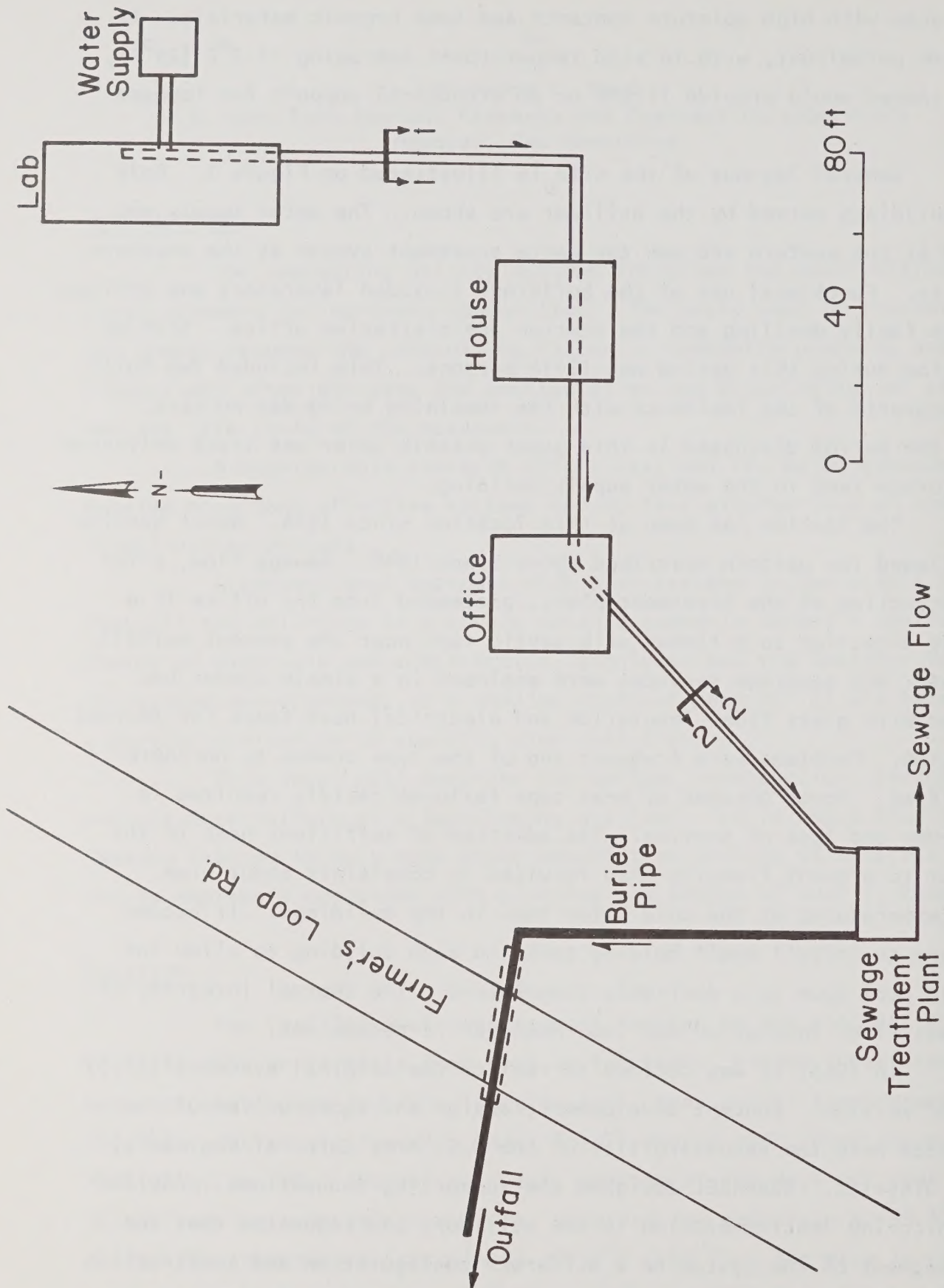


FIGURE 1 - UTILIDOR and SEWAGE TREATMENT PLANT
USA CRREL ALASKA FIELD STATION

FOUNDATIONS

The marginal thermal characteristics and ice-rich nature of the permafrost made deep burial of pipe systems impractical at this site. Shallow burial was not considered feasible due to the heaving forces that will develop during the freezing and thawing of the fine grained silty soils in the active layer. An above surface system supported on a pile foundation was therefore selected.

For lightweight structures such as utilidors (the box type in this case had a dead load of 185 kg/m (125 #/ft) the active zone heaving forces on the supporting piles are often the critical design factor. At this same location experiments have demonstrated uplift forces of up to 17,856 kg/m (6 tons per foot) of perimeter on steel piles. These forces can be controlled by minimizing the exposed surface area in the active layer and using special coatings and materials to eliminate or reduce soil adhesion to the pile. These forces can also be resisted by a sufficient depth of embedment in competent permafrost. To insure development of maximum possible resistance it is desirable to provide the maximum possible surface area for the portion of the pile embedded in the permafrost.

A combination of all of these factors was used in this case in a design developed by Mr. Frederick Crory of USACRREL. Piles were installed on 4.9 m (16 ft) centres along the length of the utilidor in augered 25.4 cm (10 inch) diameter holes. These holes penetrated to an average depth of 8.5 m (28 ft) below the surface to ensure at least 3.05 m (10 ft) of embedment in permafrost. A combination section was used for this piling as shown in Figure 2. The upper portion through the active layer was a 10.2 cm (4 inch) diameter pipe to minimize surface area exposed. The bottom section in permafrost, was a 15.2 cm (6 inch) structural steel H section capped at the bottom with a circular plate to produce maximum surface area for heave resistance.

The pile was placed in the augered hole which was then backfilled to within 1.83 m (6 ft) of the surface with a concrete sand-water slurry which was allowed to freeze back. An oil-wax-sand mixture using 90% concrete sand, and a 70-30 combination of wax and mentor oil was used as backfill, in the upper portion of the hole as a further measure to prevent adhesion in the active layer.

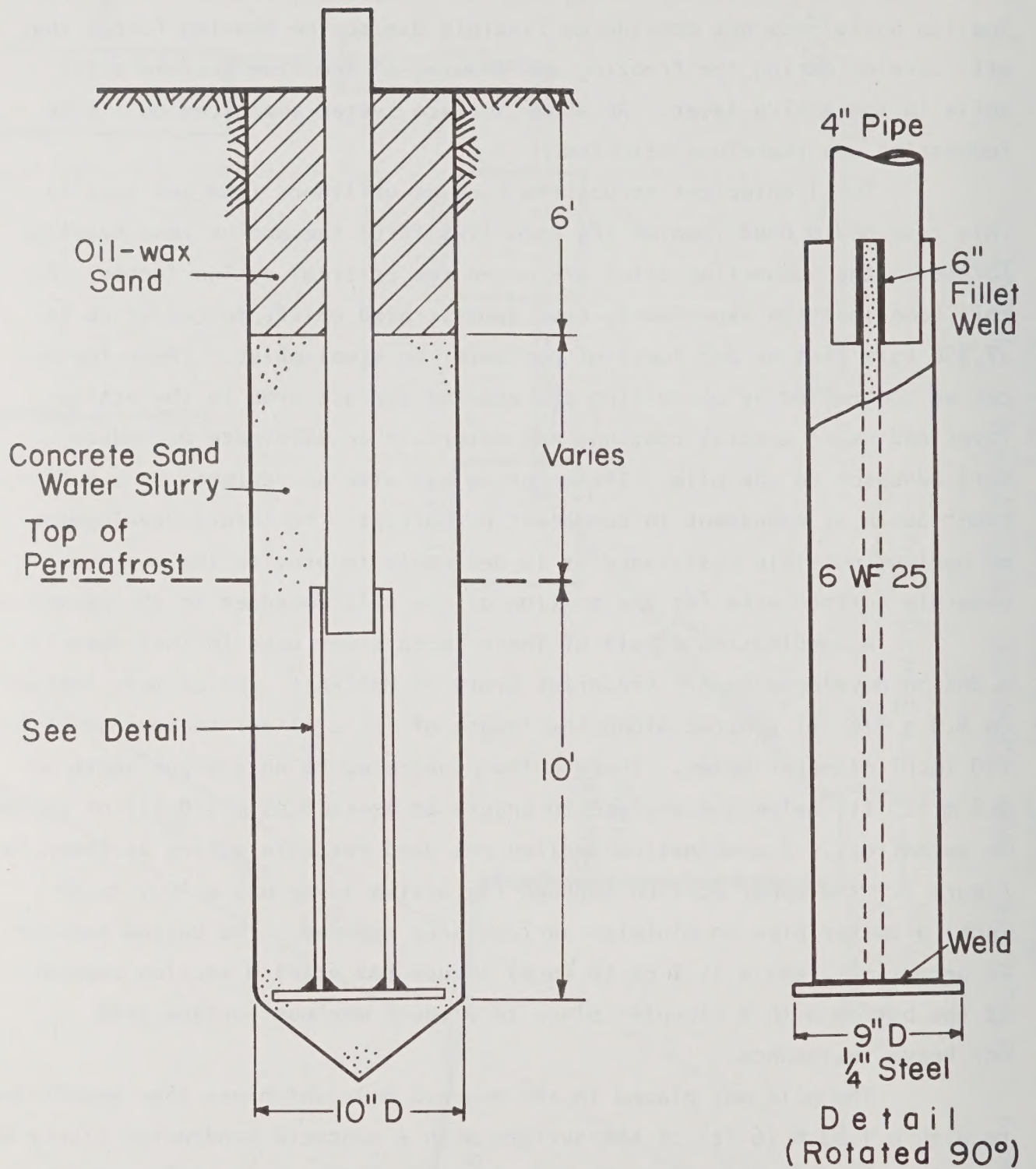


FIGURE 2. COMBINATION SECTION OF PILING

This foundation design proved to be the most successful part of the system. There were no problems with alignment or grade ever observed during the operation of the utilidor and a visual check in 1975, 10 years after construction of the system still indicates stable conditions with no evidence of heaving on any of these piles.

UTILITY SERVICES PROVIDED

Each of the buildings at the Station had a separate and adequate internal heating system and external electrical power connections. It was not considered cost effective to modify the station for a central heating system or to include electrical power distribution in the new utilidor. For construction of a completely new facility it may be advantageous to include heat and power distribution in the utilidor. For the case described, the needs were limited to water and sewerage systems with other design decisions required on construction materials and methods and selection of the operational mode to prevent freezing of the system.

The previous mode had been a single heat traced cold water line to each building. This then required separate tanks in each building for cooling and for additional heating to maintain desirable temperatures for domestic use. The sewage pipes in the previous system had also been heat traced electrically.

A possibility considered was a continuously circulating cold water system with pit orifice service connections at each building. Such systems have functioned satisfactorily for small camps and stations and for cities as large as Fairbanks, Alaska. However, in the setting described there would still be a need for heating domestic hot water in each building and for protecting the sewer line.

The approach selected by the designers was to provide both a circulating domestic hot water system and a single, flow-on-demand, cold water line. It was believed that this would eliminate the need for tanks in each building, that both domestic hot and cold water would be continuously available, and that designed heat losses from the circulating hot water system would provide the necessary thermal protection for the cold water and sewerage systems also contained in the utilidor. The concept seemed to provide a solution to particular local problems as well as offer a somewhat novel approach to thermal protection needs.

DESIGN

Figure 3 illustrates the basic configuration which emerged following concept selection. The piping system included 1.9 cm (3/4 inch) copper cold water line, 10.2 cm (4 inch) galvanized sewer, and a pair of 1.9 cm (3/4 inch) copper pipes for circulating hot water. These pipes are supported on wooden cradles to permit air circulation and to prevent compression of the insulation on the box floor.

A rigid polystyrene insulation was selected, having a rated conductivity of 0.02 BTU/ft/ $^{\circ}$ F. Design specifications required an insulation material with a conductivity not to exceed 0.025 BTU/ft/ $^{\circ}$ F and that the completed box utilidor should have a coefficient of heat transmission (O-value) not to exceed 0.1 BTU/hr/ft²/ $^{\circ}$ F. Based on these specifications the configuration shown on Figure 3, with 5.1 cm (2 inches) of insulation on all sides, was produced. Structural elements of the box were plywood and standard lumber shapes. To provide continuous access the cover was constructed as 2.44 cm (8 ft) long removable panels. Approximately 45.7 m (150 ft) of this type of utilidor were installed from the laboratory building to the office shown on Figure 1.

The design required complete on-site fabrication and assembly from standard construction materials. There was no off-site prefabrication required or attempted. Although somewhat labor intensive at the site there were no special skills involved and material costs would be the minimum possible.

It was believed that the design would permit construction by semi-skilled labor, that very desirable continuous access had been provided, that the insulation chosen would reduce if not eliminate water damage and that the piping arrangement provided both an efficient distribution scheme and thermal protection. It was hoped that it would become the prototype for military facilities elsewhere in the arctic.

This box utilidor was originally intended as the only type to be constructed. To permit comparative studies, USACRREL requested that a second type of utilidor be installed for the 30.5 m (100 ft) run between the office and the sewage treatment plant. Thermal characteristics were to be as close as possible as those specified for the type I box with off-site prefabrication of all components to the maximum degree possible.

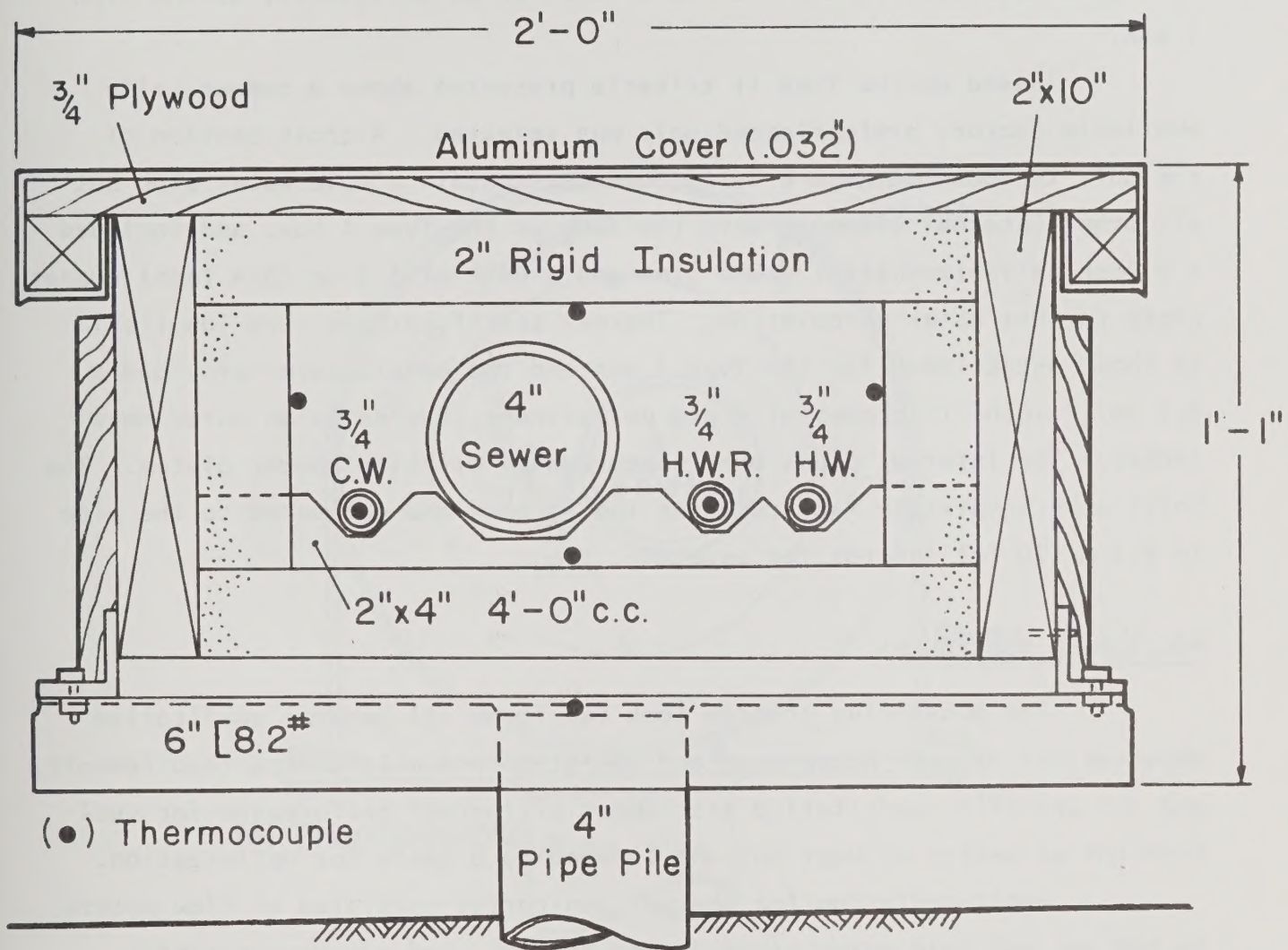


FIGURE 3. - WOODEN BOX UTILIDOR, TYPE I
(Section 1-1)

It was recognized that some sacrifices in operational access would be necessary. This type II utilidor represented the opposite condition to the Type I box in that on-site labor would be minimal but material costs (including prefabrication) high. It was assumed that the Type II could also be assembled by semi-skilled or unskilled labor and with the exception of accessibility, that it would function as efficiently as the Type I box.

Based on the Type II criteria presented above a commercially available factory prefabricated unit was selected. A cross section of the unit is shown on Figure 4. It did not contain a cold water pipe but all other internal elements were the same as the Type I box, and included a 4 inch galvanized steel sewer line and a pair of 1.9 cm (3/4 inch) copper pipes for hot water circulation. Thermal specifications were identical to those established for the Type I box and the manufacturer provided a 5.1 cm (2 inch) thickness of rigid polystyrene covered by an outer metal jacket. The internal pipes were supported by circular spacer plates. The units were completely fabricated at the factory and delivered to the site in 6.1 m (20 ft) lengths for assembly.

MONITORING PROCEDURES

The monitoring program took two forms (a) general qualitative observations of user acceptance and operation and maintenance requirements, and (b) specific quantitative assessment of thermal performance for verification of design assumptions and to provide a basis for optimization.

Instrumentation for thermal monitoring consisted of flow meters in the hot and cold water pipes at one station, and copper-constantan thermocouples monitoring fluid temperatures in the pipes and on the internal and external surfaces of the utilidor conduits. Thermocouples were placed at 3 locations: at station 1, with the flow meters, just south of the lab building; at station 2, between the office and the house; and station 3, at the mid-point of the Type II utilidor. Figures 3 and 4 illustrate the internal locations of these thermocouples. All of this instrumentation was connected to a continuous strip chart recorder. The cycling mechanism of this recorder insured that each instrumentation point could be observed at least once every three minutes. This recorder

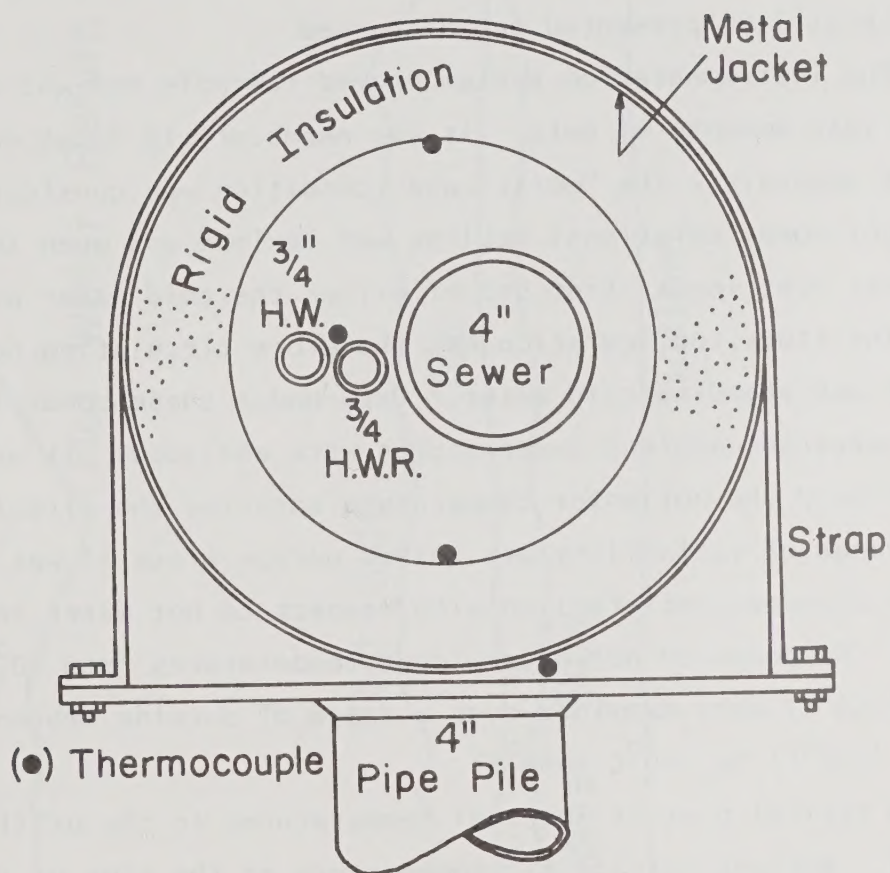


FIGURE 4. - PIPE UTILIDOR, TYPE II
(Section 2-2)

data was further reduced to a tape input for a final analysis via computer. The utilidor system and instrumentation were placed in service during December 1965 and intensely observed over the next four winter seasons. This included a failure of the system which occurred in December 1969.

PERFORMANCE ANALYSIS

A full presentation of pertinent data and calculation techniques will be given in the final report. For this paper only the results of the analysis will be presented and discussed.

The instrumentation system proved reliable and was capable of generating vast amounts of data. It was necessary to focus on selected periods for analysis. The "worst case" condition was considered to be late at night when radiational cooling was maximum and when there were no additional heat inputs from use of either the cold water or sewage systems. The study configuration was therefore circulating hot water, empty sewer and standing cold water. Data under these conditions, over a range of external ambient temperatures were analyzed. It was also possible to vary the hot water temperature entering the circulatory system. The range of variability was rather narrow since it was necessary to maintain consumer satisfaction with respect to hot water temperatures at the tap. Response to hot water input temperatures from 60°C (140°F) to 68.3°C (155°F) were examined over a range of outside ambient temperatures from -28°C ($+27^{\circ}\text{F}$) to -40°C (-40°F).

A typical plot of internal temperatures in the utilidor is shown on Figure 5. Ambient outside air temperature at the time of this run was approximately -17.7°C (0°F). The repetitious cyclic pattern of hot water temperatures is due to the thermostatic control at the heater. Such "steady state" conditions would prevail for many hours especially late at night when there were no additions or withdrawals of water.

Based on such data it is informative to construct hypothetical temperature isotherms for each utilidor type as shown in Figures 6 and 7. These are not valid in absolute terms because of discontinuities in materials and convection air currents inside the conduits. It is believed that the general pattern exhibited is valid and they can be quite revealing with respect to design assumptions.

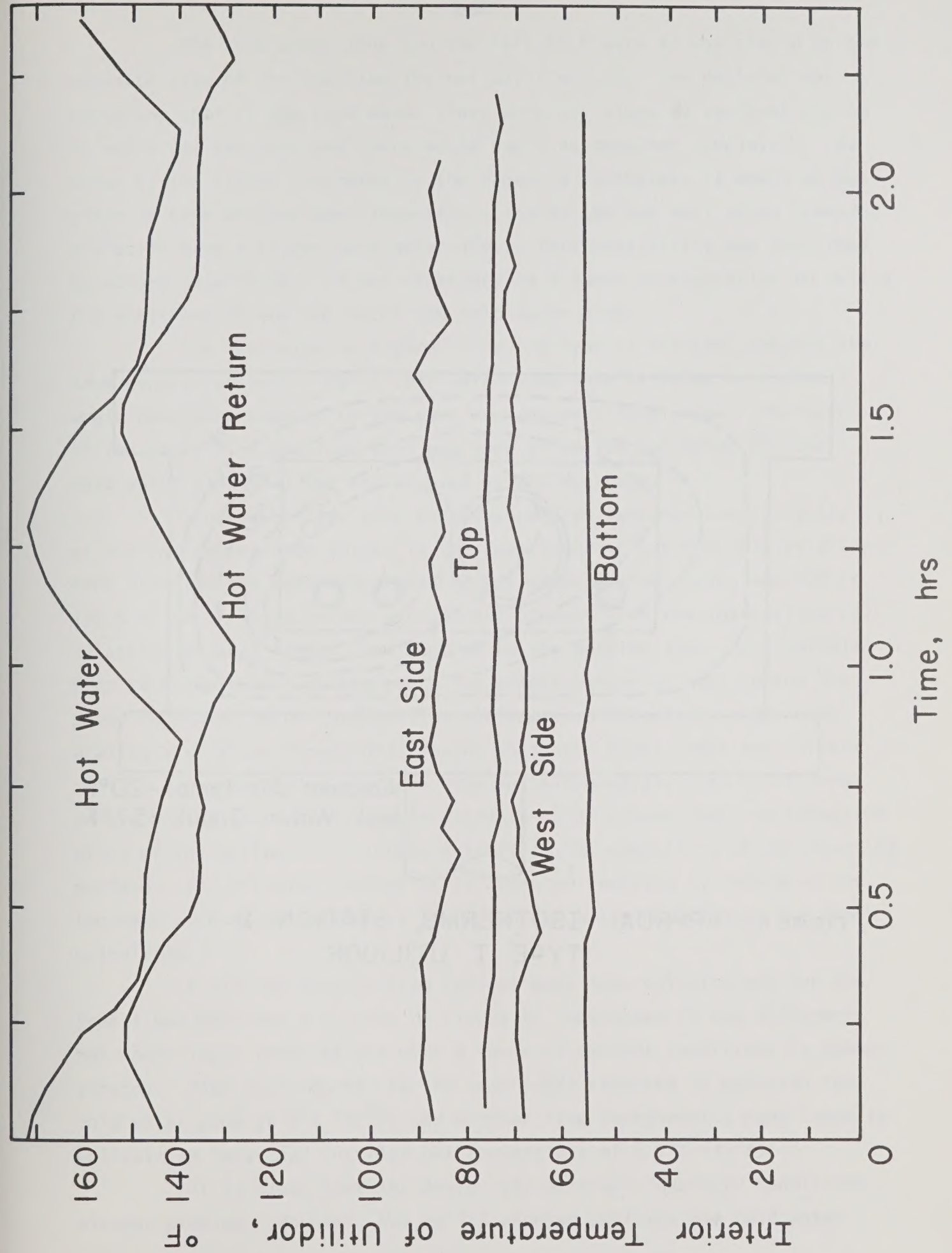


FIGURE 5. TYPICAL TYPE I UTILIDOR

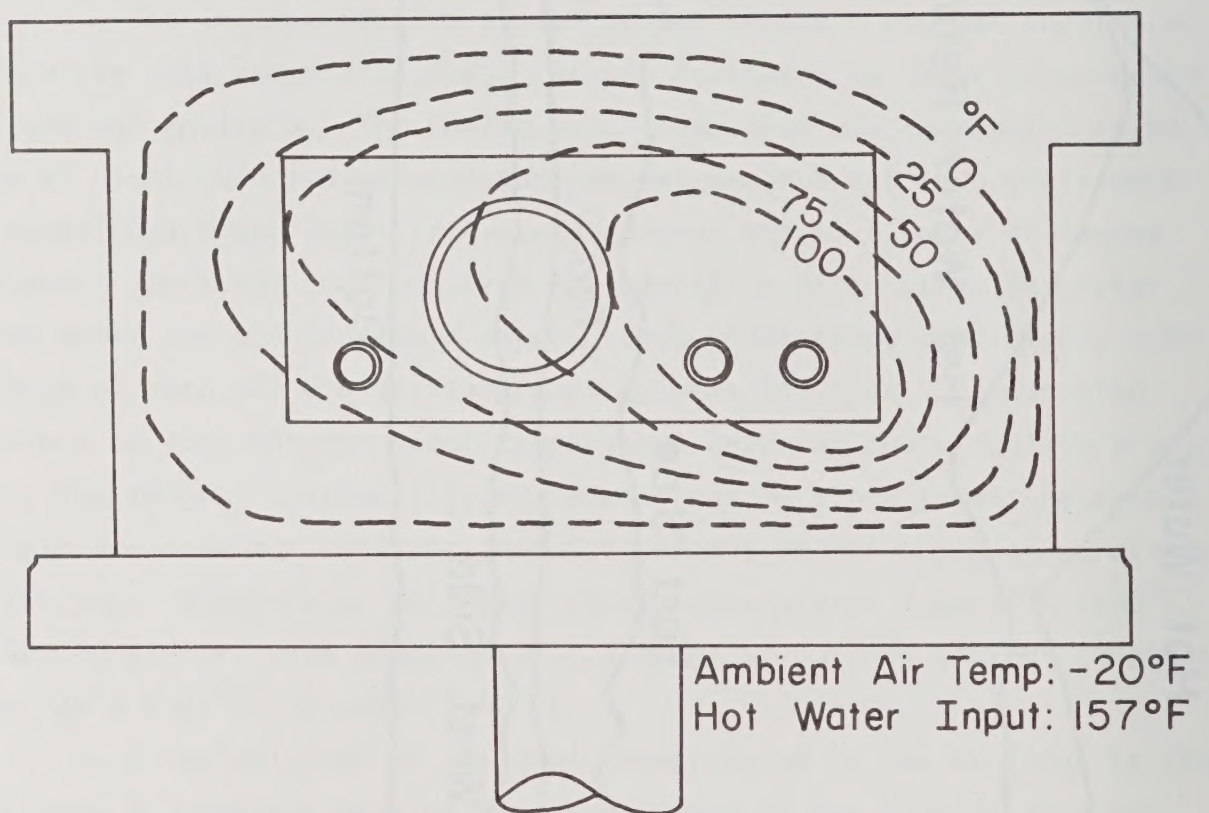


FIGURE 6. APPROX. ISOTHERMS, STATION 2
TYPE I UTILIDOR

The cold water line (on the left in Figure 6) was placed on the opposite side of the box from the hot water system. The designer was concerned that if the cold water lines were too close to the heat source it would get too warm and there would again be consumer complaints. As shown by the trends indicated by the Figure 6 isotherms, it would be possible to have an "average" temperature inside the box well above freezing and still have a frozen cold water pipe. This possibility was confirmed by actual experience. It was necessary in a later configuration to switch the positions of the hot water and cold water pipes.

The isotherms on Figure 7 for the Type II utilidor exhibit the same general pattern. Had a cold water pipe been included it probably would have been exposed to the same hazards described above. The bulk of the sewer pipe provided even one more effective shielding for the cold water pipe than was anticipated by the designer.

Since both flow rate and temperatures were measured directly at the instrumentation points in the Type I box it was possible to determine directly the heat loss from the hot water system during the 100 ft (30.5 m) run. These values agreed very closely with the theoretical calculations of heat losses from the box to the outside air. Most calculation techniques used by engineers for determination of heat losses are based on transmission through flat surfaces. Difficulties arise when dealing with three dimensional shapes that have sharp edges and corners.

A simplifying approach used in this analysis, and which seems to provide at least a reasonable estimate is to assume that the effective width of the surface of interest extends to the centerline of the abutting surface. For circular objects it is accepted practice to determine the log mean area as an equivalent flat slab for which heat losses are then calculated.

A plot of results from typical heat loss calculations for the Type I box utilidor are shown on Figure 8. Responses to two different hot water input temperatures over a range of ambient conditions is demonstrated. Also superimposed is the heat input required to maintain the cold water pipe at 0°C (32°F) and another line representing heat input to maintain an "average" interior box temperature of 1.7°C (35°F).

It is clear that the design can maintain "average" conditions without problem. However, due to its exposed position the cold water

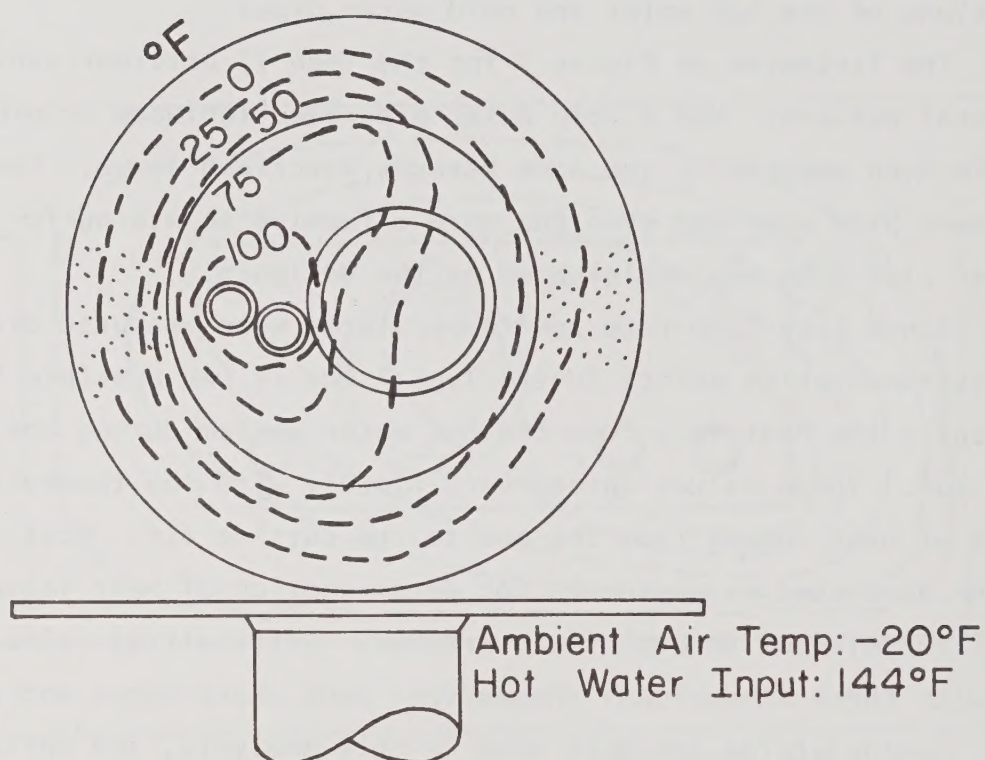


FIGURE 7. APPROXIMATE ISOTHERMS
TYPE II UTILIDOR

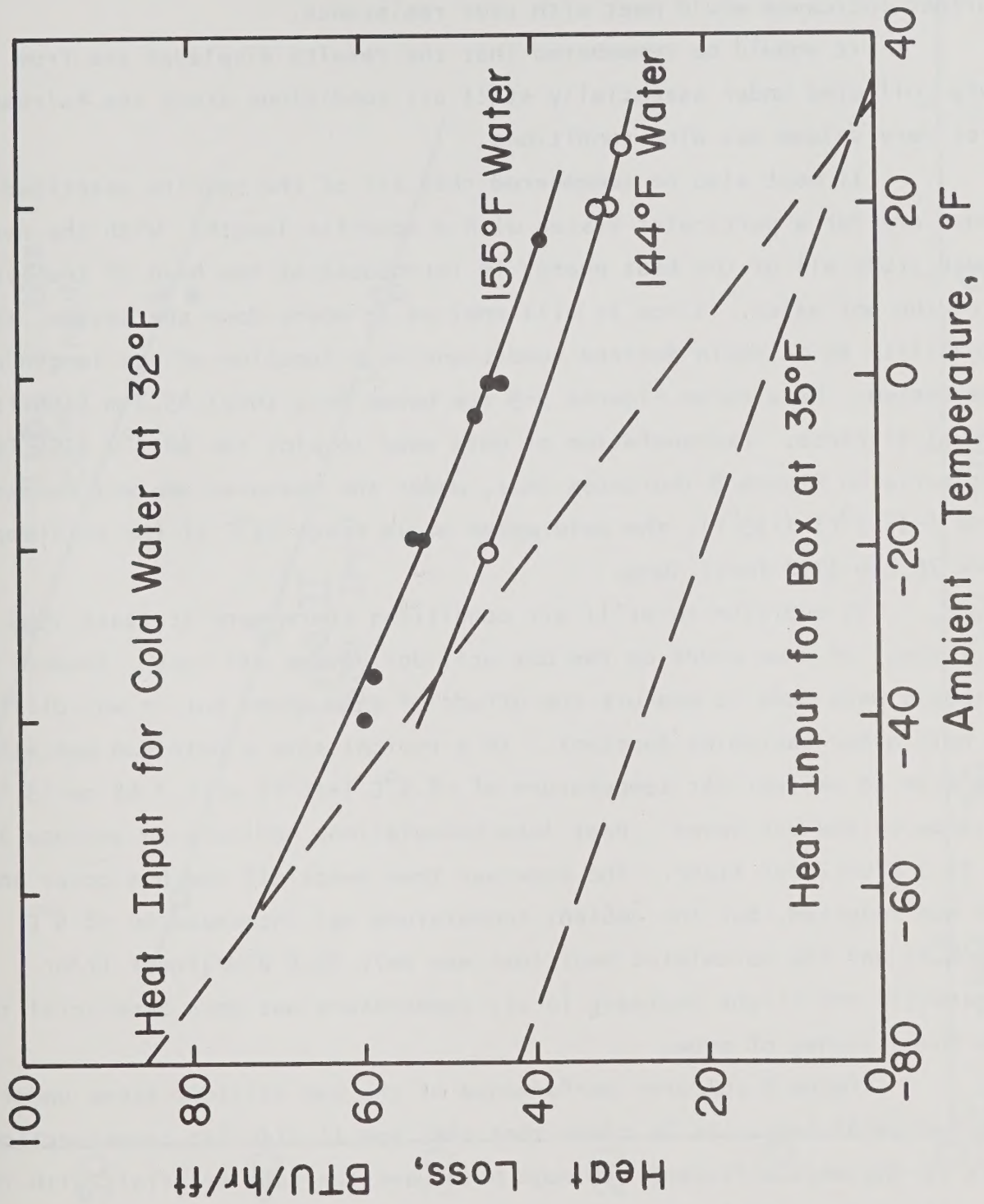


FIGURE 8. HEAT LOSS vs INPUT
Type I Utilidor Box

pipe is approaching critical conditions at the design level of -51.1°C (-60°F).

The 68.3°C (155°F) hot water input is near the upper limit of acceptable temperatures for domestic hot water use ($49-71^{\circ}\text{C}$) ($120^{\circ}-160^{\circ}\text{F}$). Further increases would meet with user resistance.

It should be remembered that the results displayed are from data collected under essentially still air conditions since the Fairbanks area very seldom has wind conditions.

It must also be remembered that all of the results described above are for a particular system with a specific length. With the case under study all of the heat energy is introduced at the head of the system with the hot water. Since it will cool as it moves down the system, the capability to maintain desired conditions is a function of the length of the system. Results on Figures 5-9 are based on a total 45.7 m (150 ft) travel distance. Extrapolation of data used to plot the 68.3°C (155°F) input curve on Figure 8 indicates that, under the measured ambient temperature (-36.1°C) (-33°F), the cold water would reach 32°F if the utilidor were 76.2 m (250 feet) long.

In addition to still air conditions there were at least 15.2 cm (6 inches) of snow cover on the box utilidor during all runs. Several attempts were made to measure the effect of snow cover but it was difficult to hold other variables constant. In a typical case a data run was attempted with an ambient air temperature of -8.9°C ($+16^{\circ}\text{F}$) with 7.62 cm (3 inches) of snow on the box cover. Heat loss calculations indicate an average loss of 31.7 BTU/linear ft/hr. The snow was then swept off the box cover and the run repeated, but the ambient temperature had increased to -8.4°C (16.8°F) and the calculated heat loss was only 29.8 BTU/linear ft/hr. Apparently the slight increase in air temperature was more beneficial than the three inches of snow.

Figure 9 compares performance of the two utilidor types under similar conditions. It is clear that the Type II circular cross section unit is the most efficient although both have the same materials with the same thermal properties specified. The controlling variable is the surface area exposed. The advantage is not in prefabrication but, in the shape of the completed unit. It is well known that a circle is the most effective way to enclose a given area with the least perimeter.

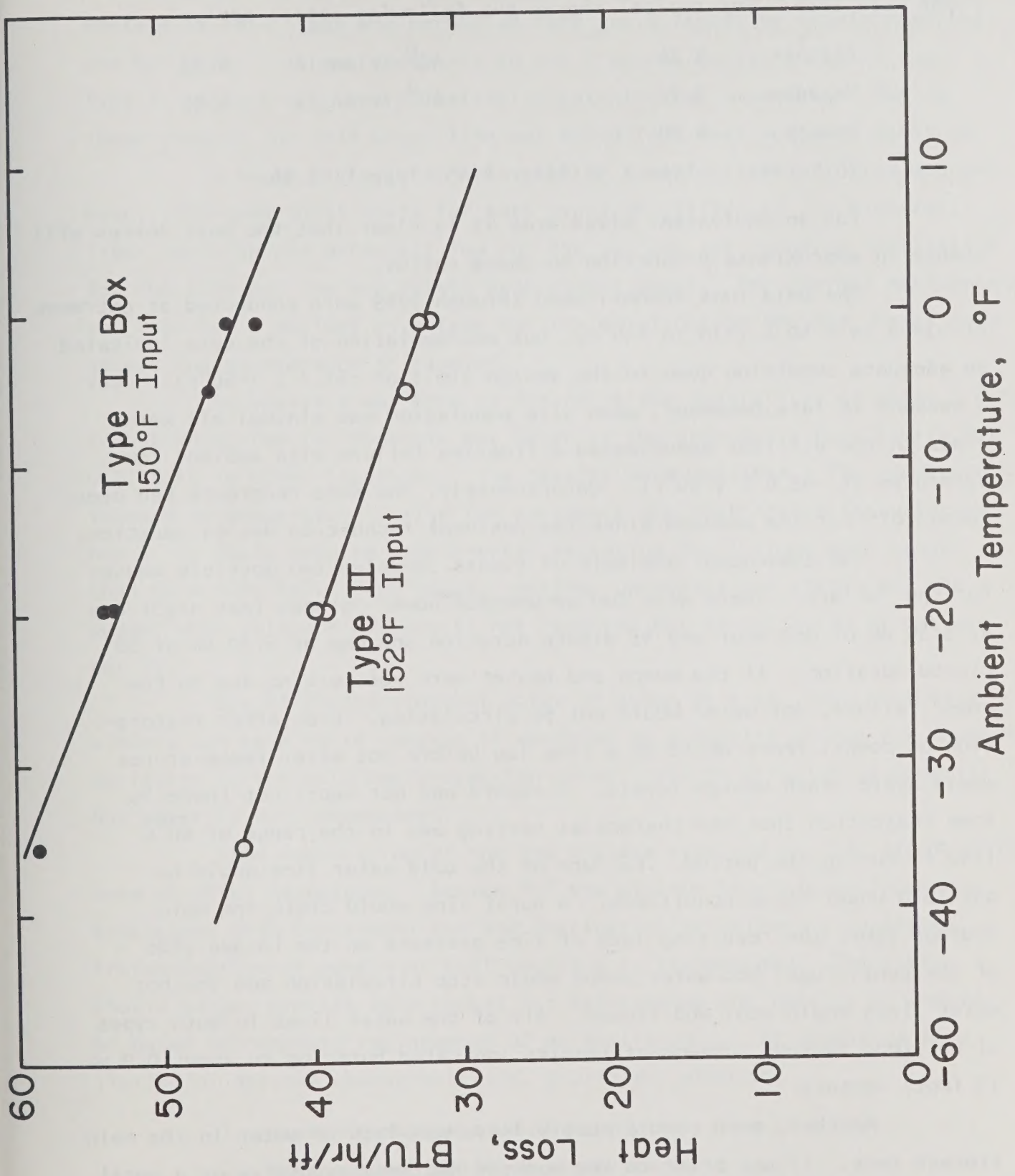


FIGURE 9. HEAT LOSS COMPARISON
Type I and II Utilidors

For regular geometric shapes the ratio of the perimeter to the square root of the area is a characteristic of the shape defined and invariant with size. For typical shapes the following ratios apply:

Circles	3.54	45° Triangle	4.83
Hexagon	3.72	60° Triangle	4.56
Square	4.00		

This case: Type I utilidor 4.45, Type II 3.54.

For an equivalent sized area it is clear that the heat losses will change in approximate proportion to these ratios.

The data runs accomplished through 1969 were conducted at extremes of -34.4 to -40°C (-30 to -40°F), but extrapolation of the data indicated an adequate condition down to the design limit of -51.1°C (-60°F). Over a weekend in late December, when site population was minimal all water lines in the utilidor experienced a freezing failure with ambient temperatures of -45.6°C (-50°F). Unfortunately, the data recorders had been turned off for the weekend since the resident technician was on vacation.

The subsequent analysis of events revealed two possible causes for the failure. There were two documented power outages that night one at 3:30 AM of one hour and 45 minute duration and one at 5:50 AM of 20 minute duration. If the pumps and heater were not working due to the power failure, hot water would not be circulating. Even after restoration of power, there would be a time lag before hot water temperatures would again reach design levels. A record was not kept, but there is some indication that the thermostat setting was in the range of 60°C (140°F) during the period. Failure of the cold water line would be possible under these conditions. A burst line would drain the main storage tank, the resulting lack of line pressure on the intake side of the centrifugal hot water pumps would stop circulation and the hot water lines would cool and freeze. All of the water lines in both types of utilidor failed, subsequent repairs indicated bursting on about 0.9 m (3 foot) centers.

Another, more remote possibility, was lack of water in the main storage tank. If use prior to the weekend had been excessive or a small leak developed in the plumbing, all of the water available could have been consumed or lost. This would produce the same failure responses discussed previously.

Repairs to the system were made as soon as weather permitted. The continuous accessibility of the Type I utilidor was a significant advantage at this stage and permitted very rapid repair by simply removing the box cover. It was necessary to cut frequent access holes in the Type II conduit and then do extensive patching and rewelding. During these repairs the cold water line was moved to a more protected location.

A rough analysis at this time of construction indicated approximately the same total costs for both types of utilidors. As expected, labor was high and materials low for the box and the opposite combination for the tube but the two totals were almost equal. For thermal performance the tube had a decided advantage but its construction did not permit easy access for maintenance or repairs.

An analysis was done to determine the feasibility of using a distribution system for domestic hot water as the protective heat source for utilidors in other locations. The results were negative. The constraints imposed on temperature limits for consumers are restrictive for utilidor heat. It would require supplemental reheating for systems much longer than 61 m (200 ft). Heat losses continue unnecessarily throughout the summer when utilidor heating is not required but distribution of hot water is.

Use of circulating hot water or steam as a utilidor protective element can be a valid concept if designed as a heating source for connected buildings or for utilidor protection alone. Use of circulating domestic hot water is not recommended.

Some combination of the two systems examined in this study would seem to offer advantages. Design for the minimum possible surface area consistent with functional use and fabrication technique is suggested. Prefabrication of panels or half sections is recommended. The design should either provide easy access for maintenance and repairs or should be based on complete replacement of an entire unit. To summarize in a listing of desired characteristics, a utilidor should:

1. have minimum exposed surface;
2. have maximum possible accessibility;
3. have a high degree of prefabrication; and,

4. have easy replacement of components
or of entire section.

In addition, the designer must expect the unexpected.

REPORT ON NEW
FROBISHER BAY UTILIDOR PHASE I

by

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Northwest Territories

Before going into the various aspects of the Frobisher Bay Utilidor system I would like to preface my remarks by saying that firstly: I am relatively new and inexperienced in northern work having only been in Yellowknife a little over a year. However, during the past year I have been involved in major projects throughout the Territories and one point that has hit home to me concerning various design approaches is that each location has to be assessed on its own merit. The system such as the one at Frobisher Bay will not necessarily work in Inuvik or Norman Wells. The above ground utilidor systems in the latter two communities would not be appropriate as well as too expensive in Rankin Inlet. While the Frobisher Bay system would work in Rankin Inlet, it would be more expensive than other underground systems that will work equally as well. Therefore, one must look at the Frobisher system as the best design choice for its given location. This is not to rule out its application in other similar circumstances.

Frobisher Bay is a community of approximately 2,500 people located in the eastern arctic on southern Baffin Island. As a result it is well above the tree line and in a continuous permafrost zone.

In December of 1972 a Planning and Engineering Report was prepared for the Hamlet of Frobisher Bay. The 1972 report was a preliminary engineering report into the feasibility of providing piped water and sewer services for the Hamlet. In March of 1974 a more comprehensive and detailed design report for sanitary sewers, water mains and wastewater treatment was carried out by J.L. Richards and Associates Ltd. of Ottawa.

The design report resulted in the commencement of Phase I, the first of eight phases in the summer of 1975. This presentation will concern the various design details of Phase I, as well as a brief look at the design changes which will be incorporated into Phase II.

Present System - The present water supply source is Geraldine Lake which is located due north and approximately 300 feet vertically above the townsite. The water supply flows via a treatment plant on the hill to the town by gravity with a pressure gradient throughout the townsite varying between 100 to 140 psi.

The water is delivered by means of an above ground utilidor consisting of corrugated metal boxes on piles. Sewage is discharged in a similar manner through a number of outfalls direct to the sea. Water is pre-heated at the treatment plant and continually circulated in the lines. The above system was built originally by the Americans in the early to mid-sixties to service their military installations and airport complex. It has subsequently been modified to accommodate major community buildings such as the hotel, office complex, recreation-commercial complex, row housing, hospital, schools, etc. The vast majority of individual houses are, however, still on pump-outs or honey bucket.

The existing above ground utilidors continue to be an annual maintenance headache. In addition to normal operating costs, major improvement expenditures of over \$600,000 annually have been required in the last two to three years and will also be required in the next few years in order to keep the system operational.

The New Utilidor System - Although tying into the existing system, the new system will be below ground rather than above. Continual circulation of pre-heated water throughout the water service mains will continue to be used in the new system. All sewage lines will be directed to a single outlet where eventually a sewage treatment plant will be constructed.

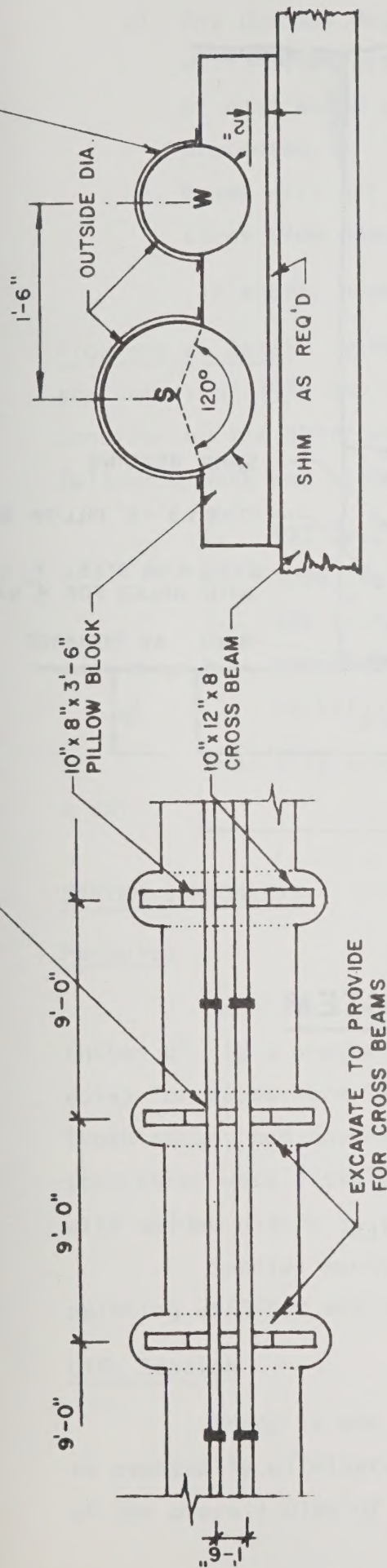
The major points concerning the new utilidor system are:

1. Utilization of standard design components of a southern system in a continuous permafrost area, i.e. standard concrete manholes. Hydrants and trunk line pipe connections. Standard sewer line gradients are used.
2. The entire system - pipes, manholes, lift stations, etc. - are tied to the permafrost by means of structural beams. The purpose of the beams is two-fold (see Figures 1 and 2).

PLACE ON ADDITIONAL
HEAT SHRINK SLEEVE
AT EACH CRADLE

WIDENED
STEEL STRAP

471



PLAN

DETAIL OF PIPE

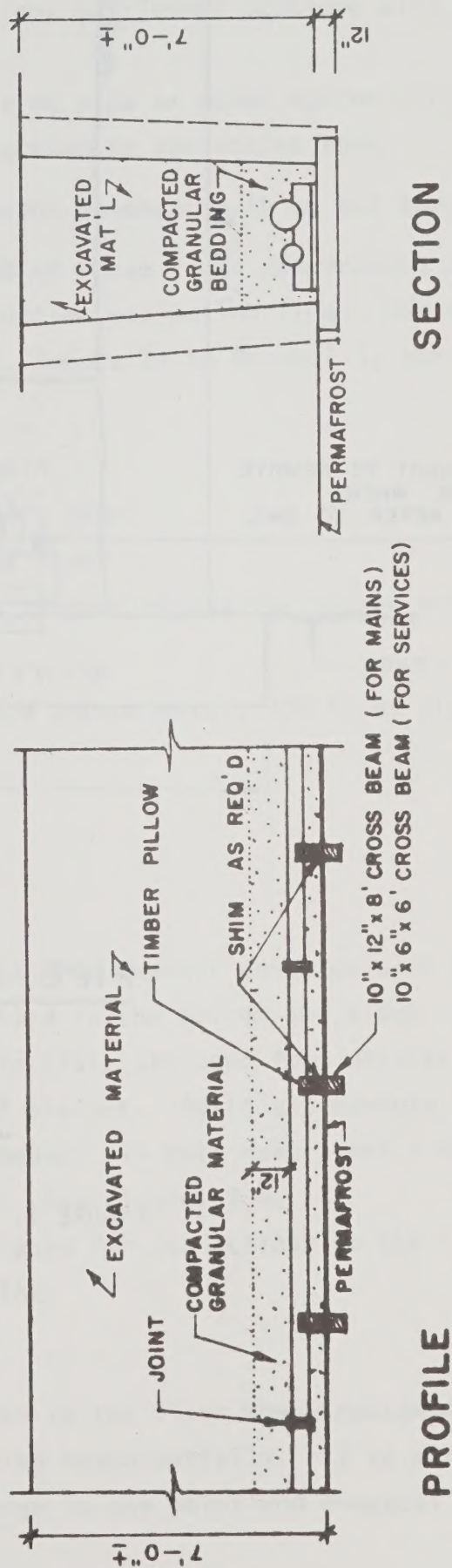
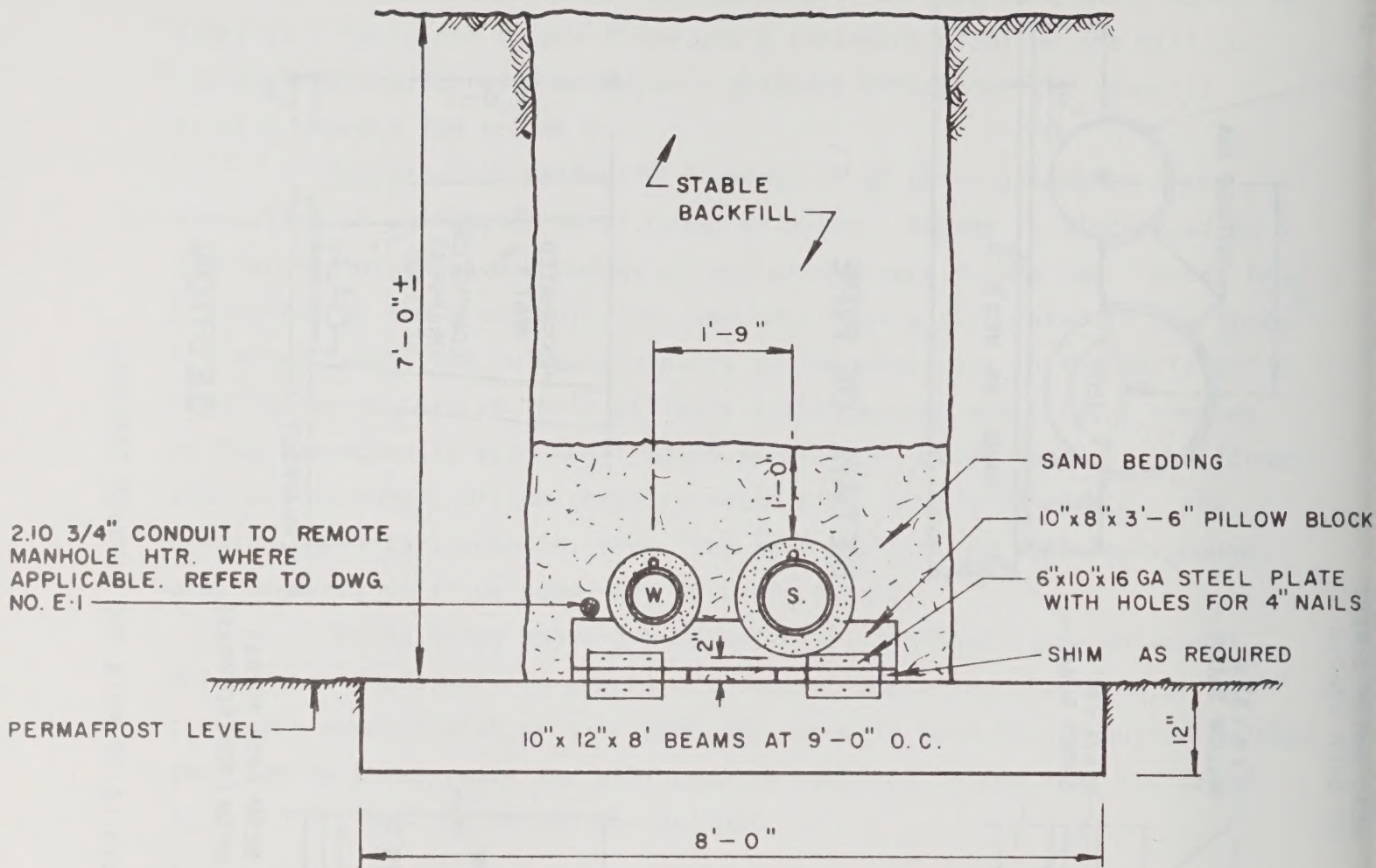


FIGURE 1. DETAILS OF MAIN AND SERVICE TRENCHES



PIPE SUPPORT SYSTEM

FIGURE 2. PIPE SUPPORT SYSTEM

- a) Any thermal degradation due to heat loss from piles or structures will not affect system since beams will transfer load to a point of unaffected permafrost. Thus, any settlement problems will be prevented.
- b) Beams will act as anchors preventing pipe or other system structures from heaving due to frost action in the active zone.

In short, beams will act to prevent movement both up and down.

Progress to Date: Unfortunately only 50% of Phase I was constructed during the summer of 1975 and none of the construction was put on line. However, considering the short construction season, August 21 to October 5, the following work was accomplished:

- 1. 597 feet of 6 inch force main
- 2. 1098 feet of 10 inch sanitary sewer
- 3. 360 feet of 8 inch sanitary sewer
- 4. Complete footing and walls of pumping station poured and backfilled.

Generally they were able to place approximately 200 ft of pipe a day.

SYSTEM COMPONENTS

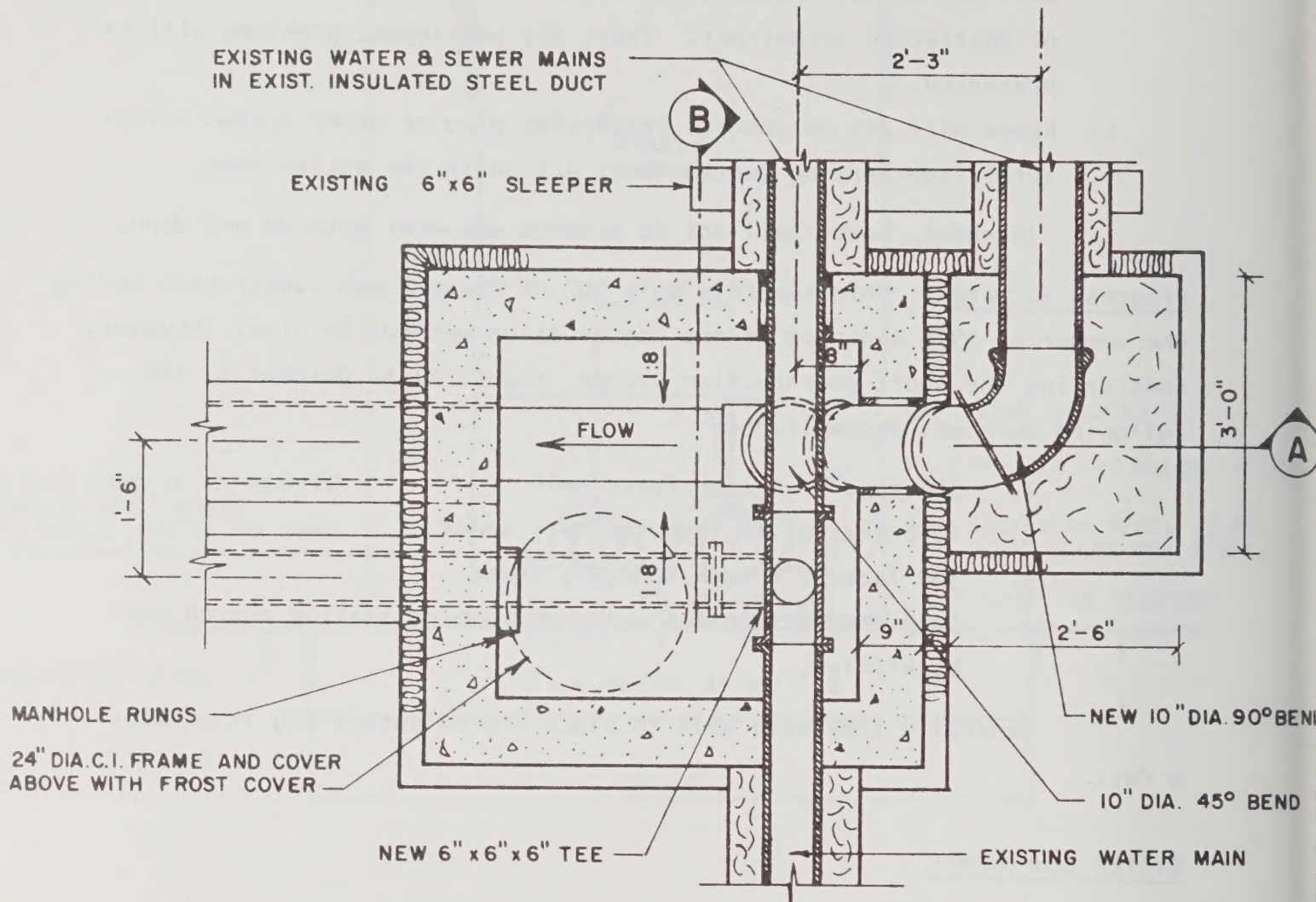
Manholes

Manholes used were generally standard precast manholes with 3 inches of rigid urethane foam sheets applied to the bottom and sides. Holes for pipes were filled with poured in place urethane foam utilizing froth packs, and covered with water-proof sealant. Again all manhole structures were installed on structural beams. In this case steel I beams with welded plates at the ends were used. See Figures 2-6.

Special manholes had to be designed for connections to the existing utilidor and existing outfall line.

Lift Station

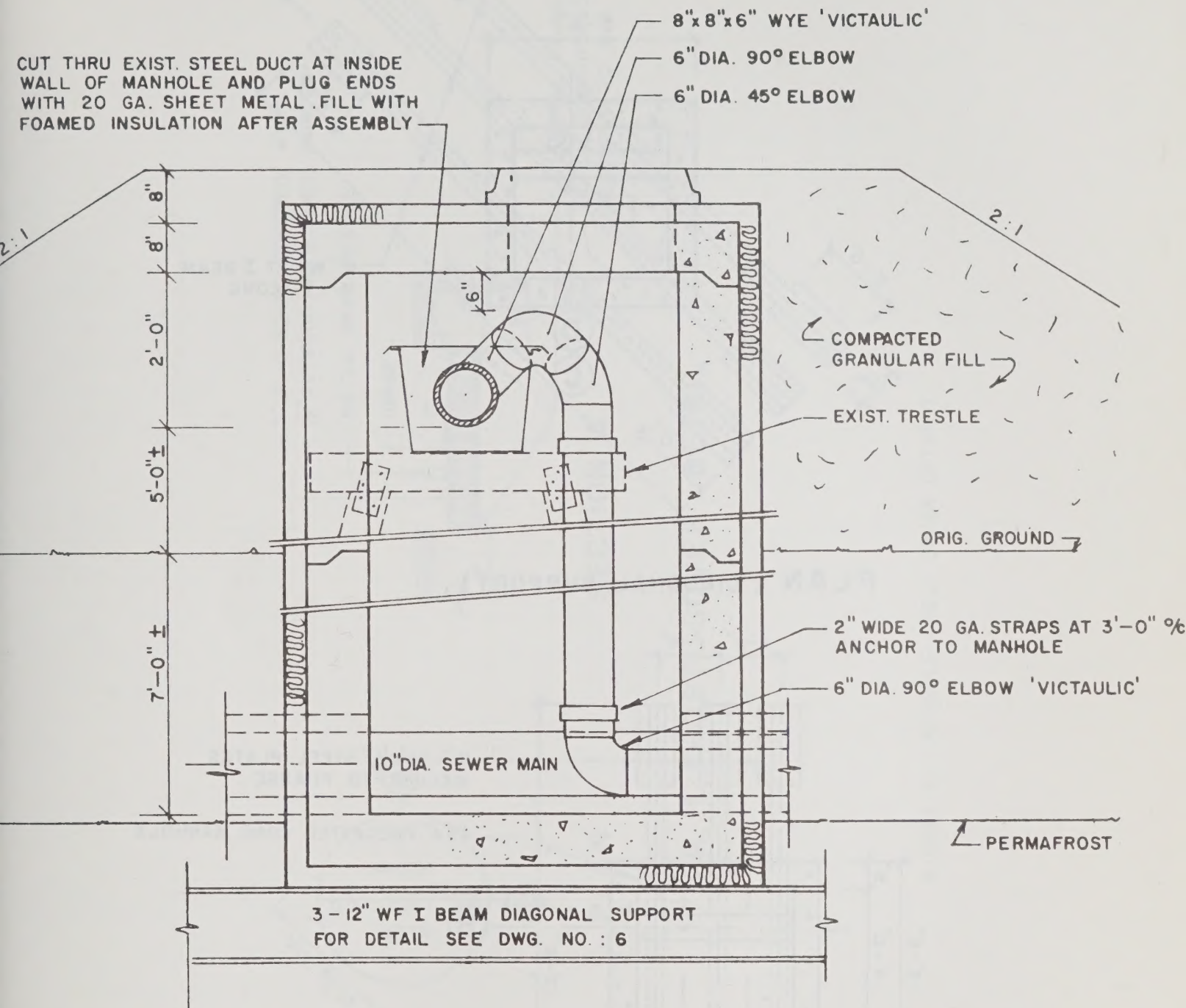
There is one sewage lift station in the first phase designed to eventually eliminate two of the existing beach outfalls. It is part of the overall plan of directing the sewage to one point and eventual



PLAN

MANHOLE NO. 9 AT EXISTING UTILIDOR

FIGURE 3. PLAN VIEW OF MANHOLE NO. 9 AT EXISTING UTILIDOR



SECTION 'A'

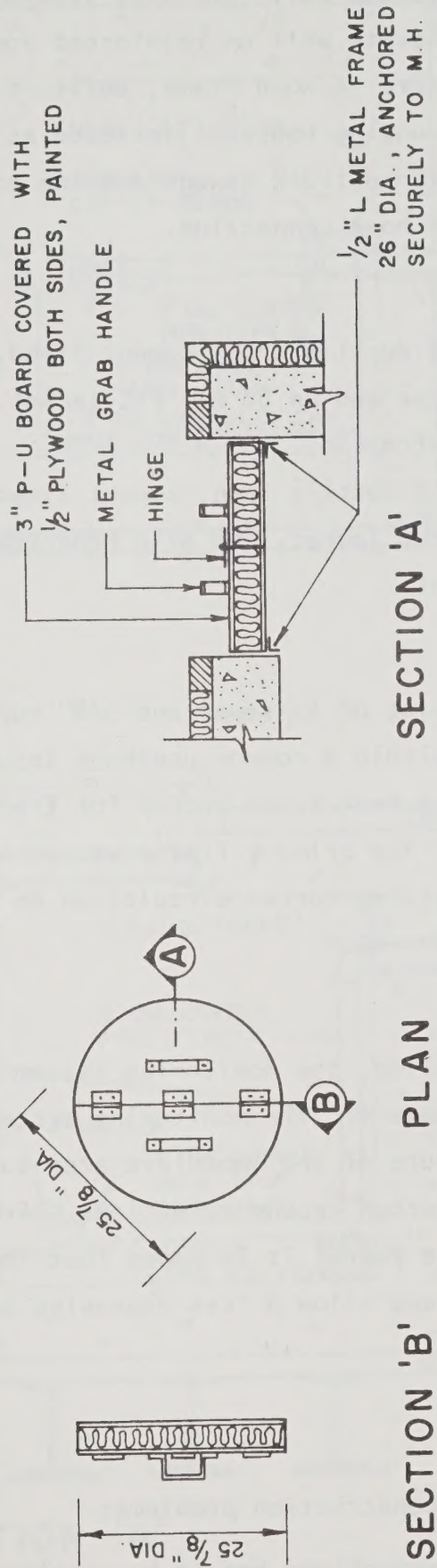
FIGURE 4. SECTION VIEW OF MANHOLE NO. 3 SHOWING FORCE MAIN INLET INTO SEWER MAIN

Technical drawing of a manhole section, labeled (B). The drawing shows a cross-section of a 4' x 4' precast concrete manhole. The manhole is surrounded by a 13'-6" high concrete wall. The manhole opening is 4'-0" wide and 5'-6" high. The manhole is supported by 12" x 24" x 1/4" steel plates welded to the flange. The manhole is also surrounded by a 2'-0" high concrete wall. The manhole is shown with a 12" diameter opening. The drawing includes dimensions for the manhole opening, the concrete wall, and the steel plates. The manhole is labeled (B).

Dimensions and components shown in the drawing:

- Manhole opening width: 4'-0"
- Manhole opening height: 5'-6"
- Concrete wall height: 13'-6"
- Steel plates: 12" x 24" x 1/4" STEEL PLATES WELDED TO FLANGE
- Manhole label: (B)
- Concrete wall thickness: 2'-0"
- Manhole opening diameter: 12"

FIGURE 5. PLAN VIEW OF TWO MANHOLE SUPPORT SYSTEMS USED



M. H. FROST COVER DETAIL

FIGURE 6. MANHOLE FROST COVER DETAILS

treatment prior to its passage to the bay. The lift station consists of a poured in place reinforced concrete well on reinforced poured in place concrete beams. The superstructure is wood frame, built in place, and designed to conform to the surrounding houses. Included as part of the lift station is a specially designed truck sewage dumping point with an exterior access for the truck hose connection.

Pipe

Watermains are Class 3 ductile iron, cement lined, victaulic grooved, with 3 inches of urethane and an 80 mil PVC jacket, fully heat traced, and thermostatically controlled.

Sewer mains are Class 2 ductile iron, cement lined, tyton joints, with 3 in. of urethane, 80 mil PVC jacket, and also heat traced in a similar manner to the water mains.

House Connections

House connections consist of 4" sewer and 5/8" supply and return copper water lines all bundled within a common urethane insulation and plastic jacket. The system has a heat trace backup for freezing which is thermostatically controlled. The primary freeze protection is a circulating pump in the houses providing forced circulation on the supply and return lines. See Figures 7 - 10.

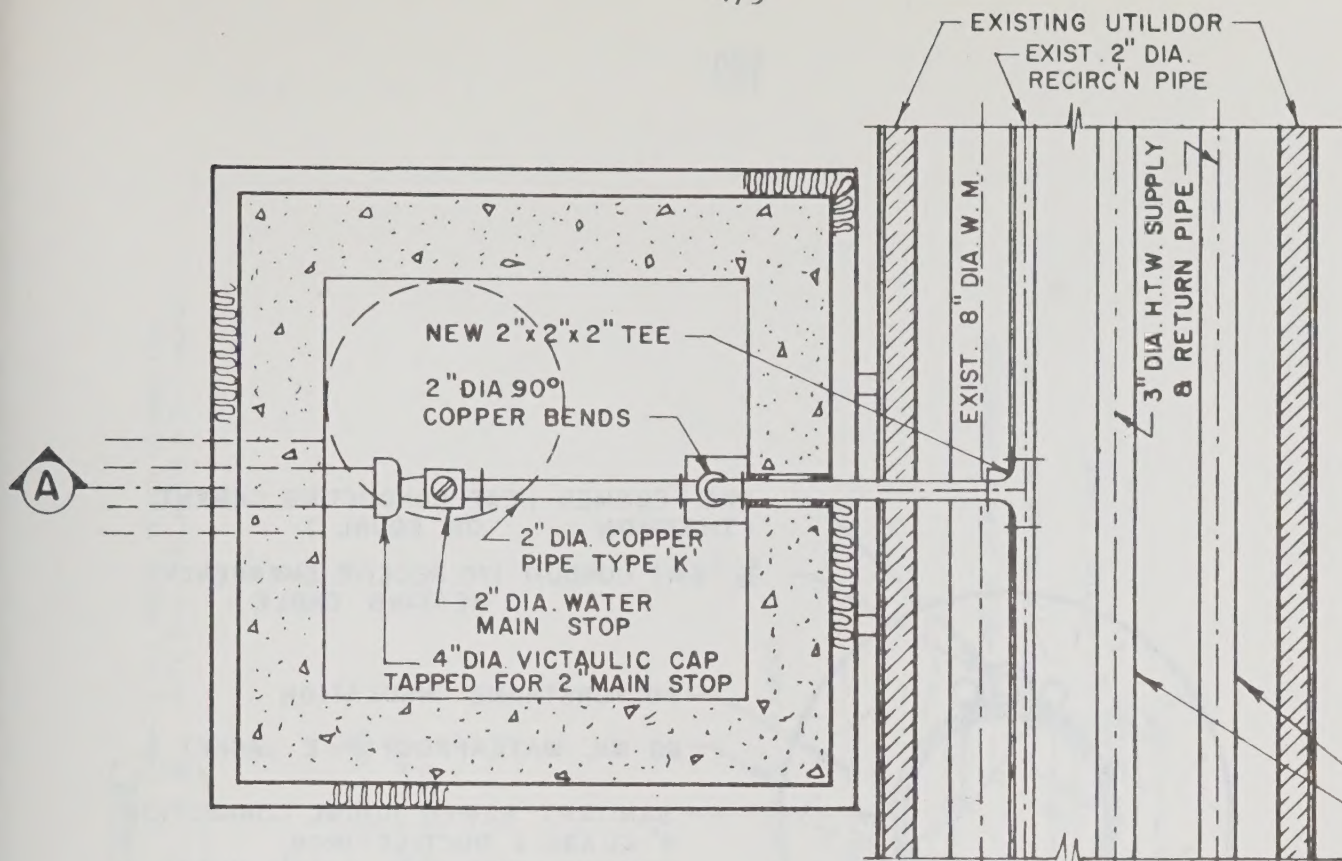
Monitoring System

Although not yet installed, the monitoring system will be located at two separate points in Phase I. The monitoring system is designed to give an accurate thermal picture of the immediate area surrounding the pipes and compare this to undisturbed ground conditions. From the information obtained over two to three years, it is hoped that the design can be modified accordingly and perhaps allow a less expensive approach. (See Figure 12).

CONSTRUCTION PROBLEMS

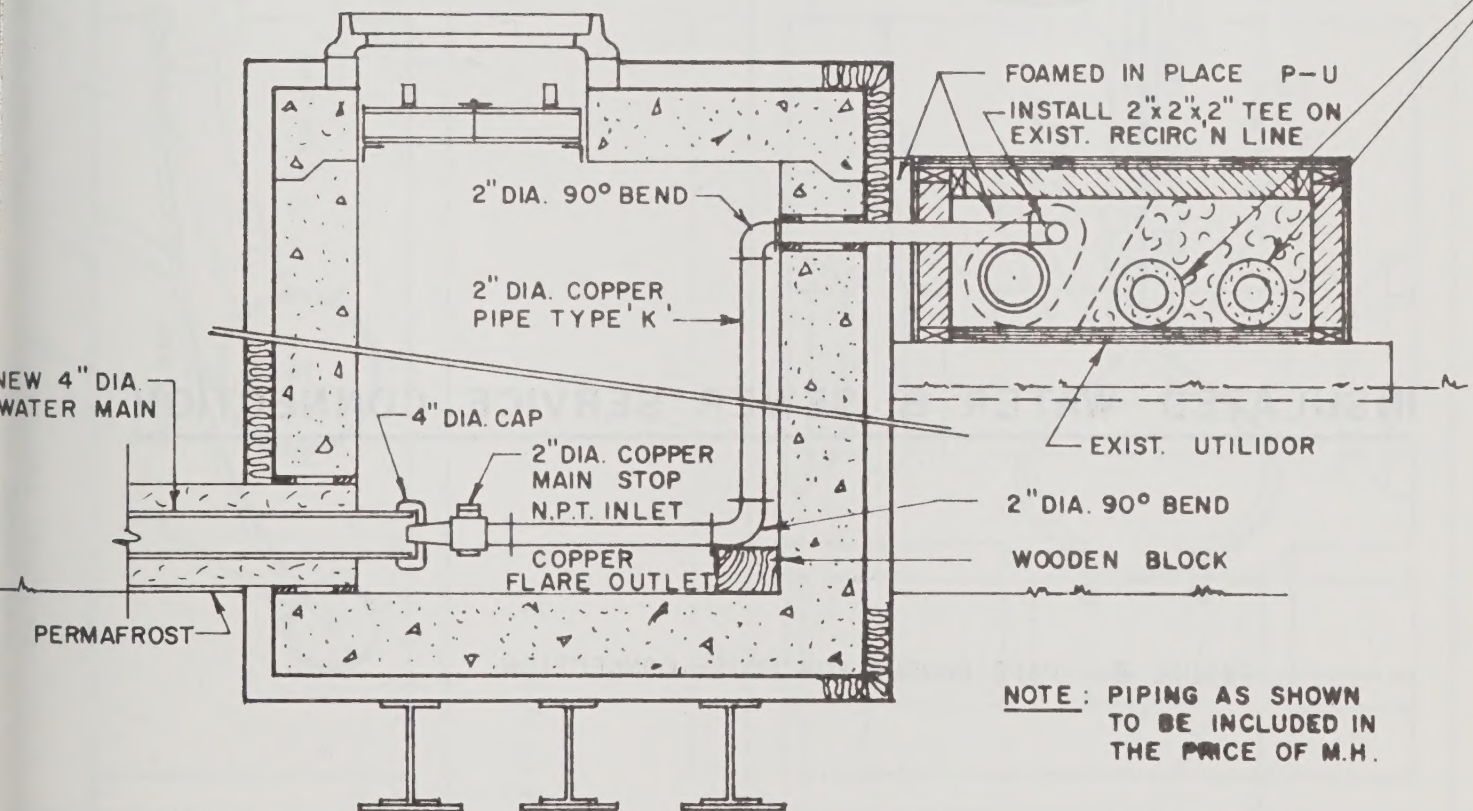
There were three main construction problems:

Dewatering: All trenches and excavations had to be continually pumped out, due to the constant flow of groundwater in the active layer.



PLAN

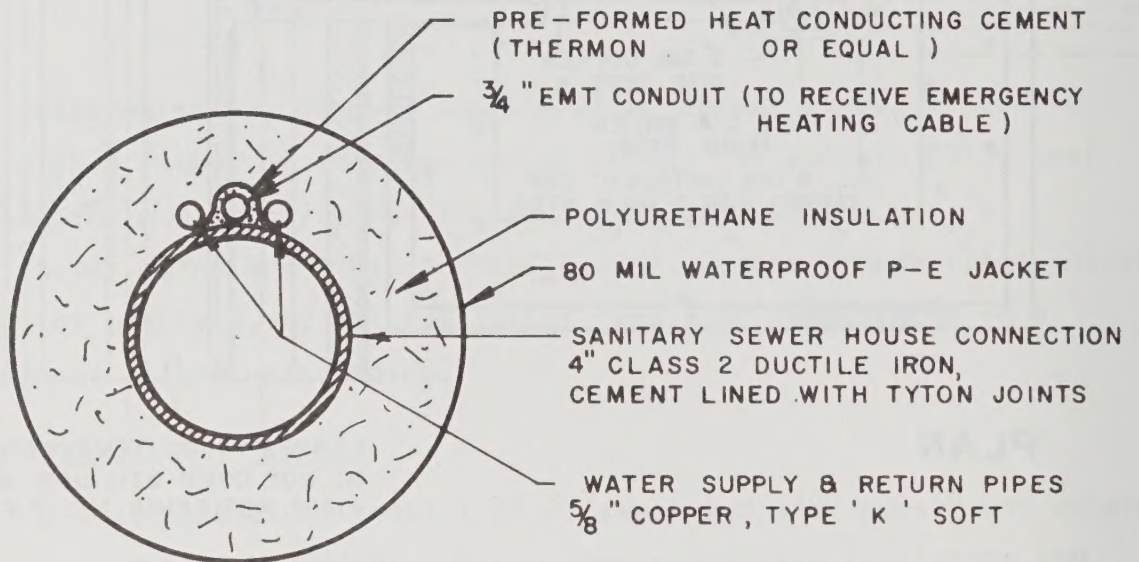
DANGER ! HIGH TEMPERATURE WATER.
DO NOT OPEN UTILIDOR WITHOUT
FIRST NOTIFYING N.C.P.C.



NOTE : PIPING AS SHOWN
TO BE INCLUDED IN
THE PRICE OF M.H.

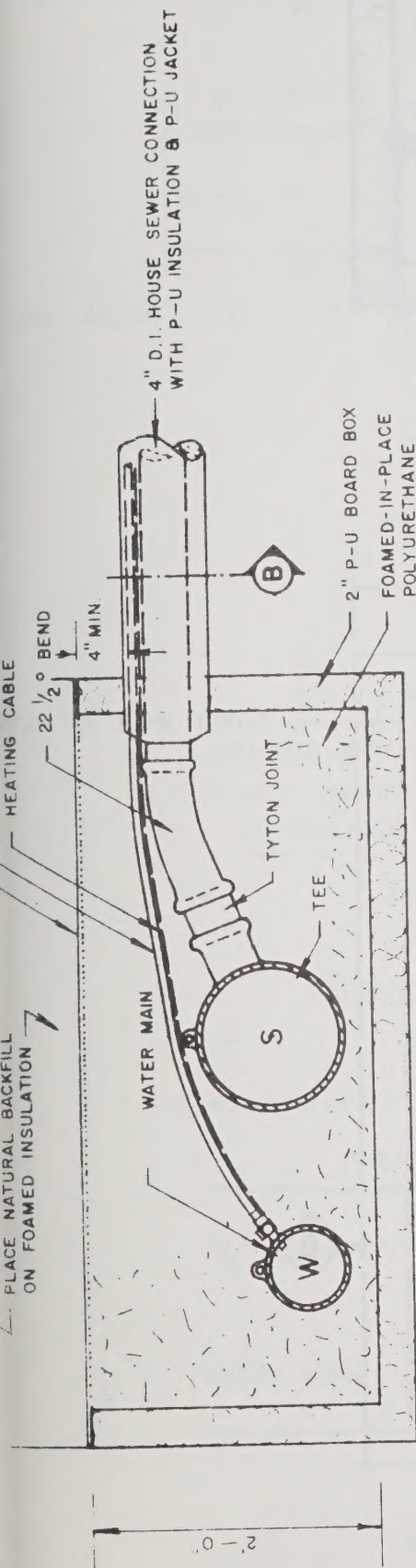
SECTION 'A'

FIGURE 7. MANHOLE # 16 - WATER RECIRCULATION PIPE DETAILS



INSULATED WATER & SEWER SERVICE CONNECTION

FIGURE 8. PIPE BUNDLE FOR HOUSE CONNECTION



SECTION 'A'

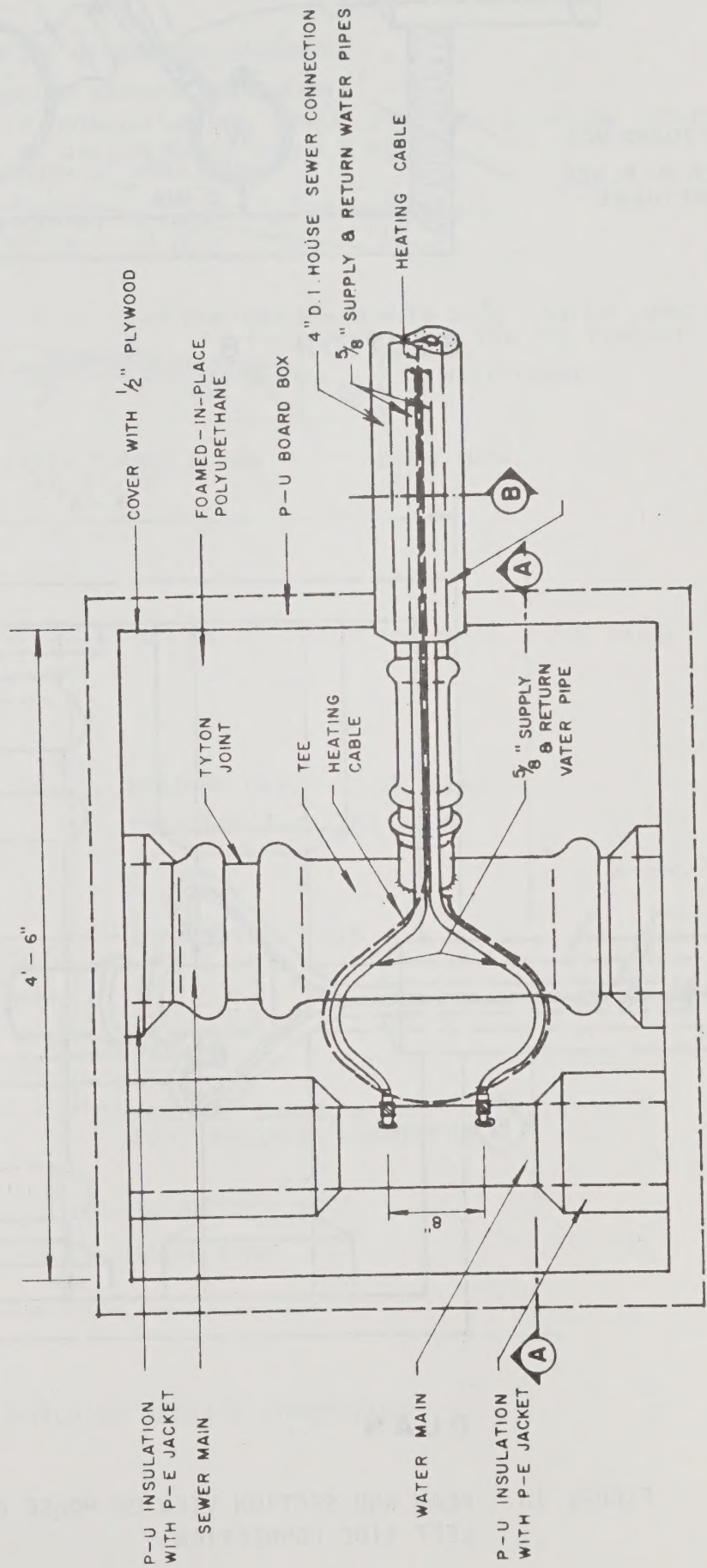
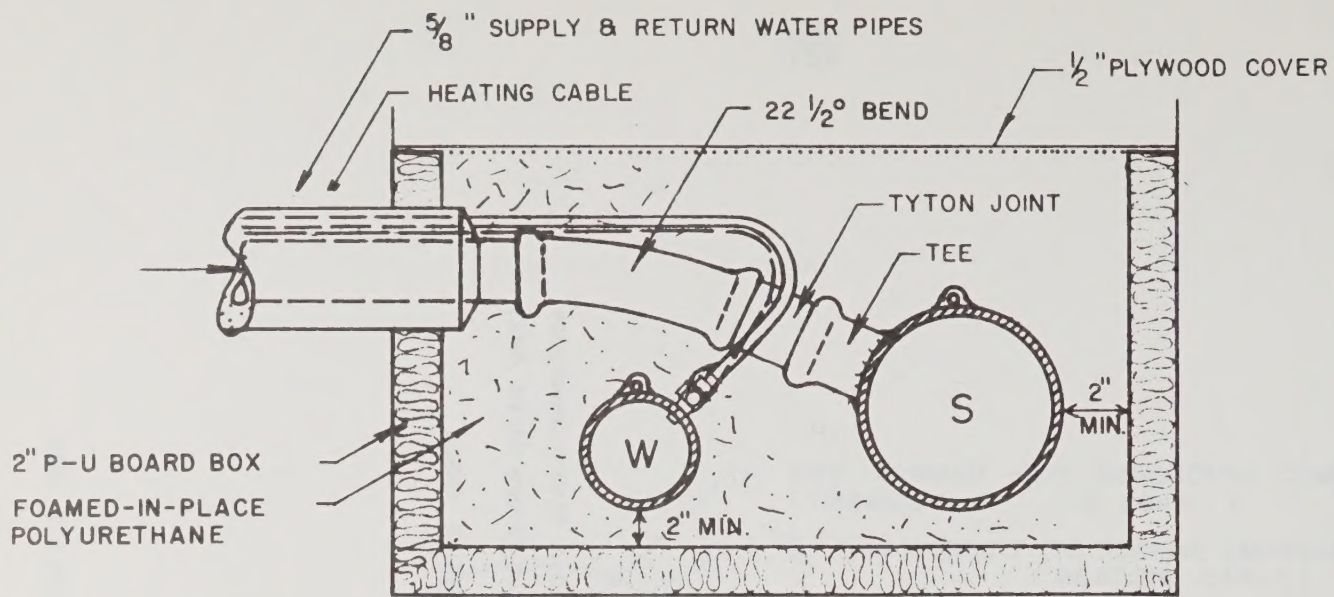
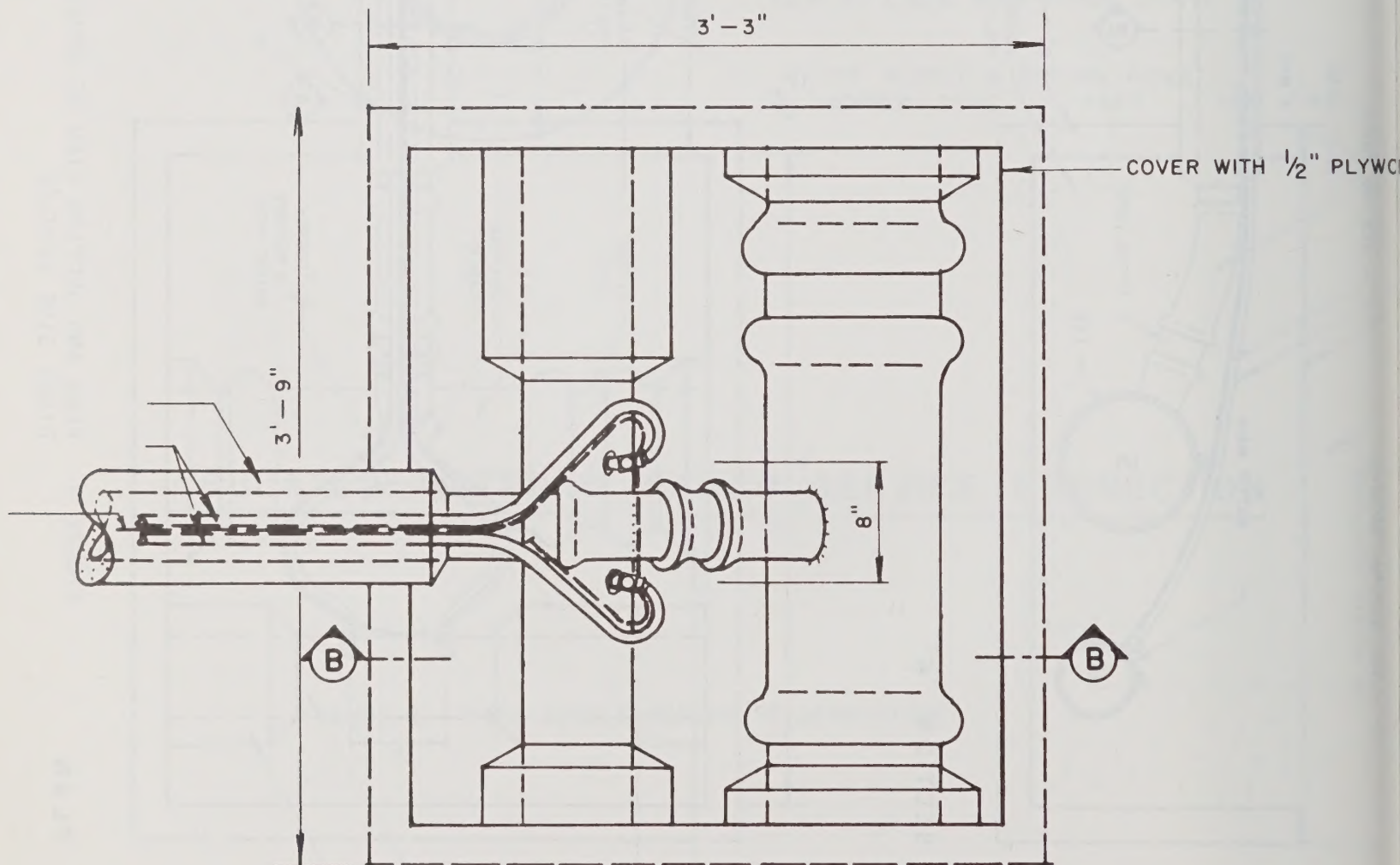


FIGURE 9. PLAN AND SECTION VIEW OF HOUSE CONNECTION SERVICE BOX. RIGHT SIDE SERVICE



SECTION 'B'



PLAN

FIGURE 10. PLAN AND SECTION VIEW OF HOUSE CONNECTION SERVICE BOX.
LEFT SIDE CONNECTION

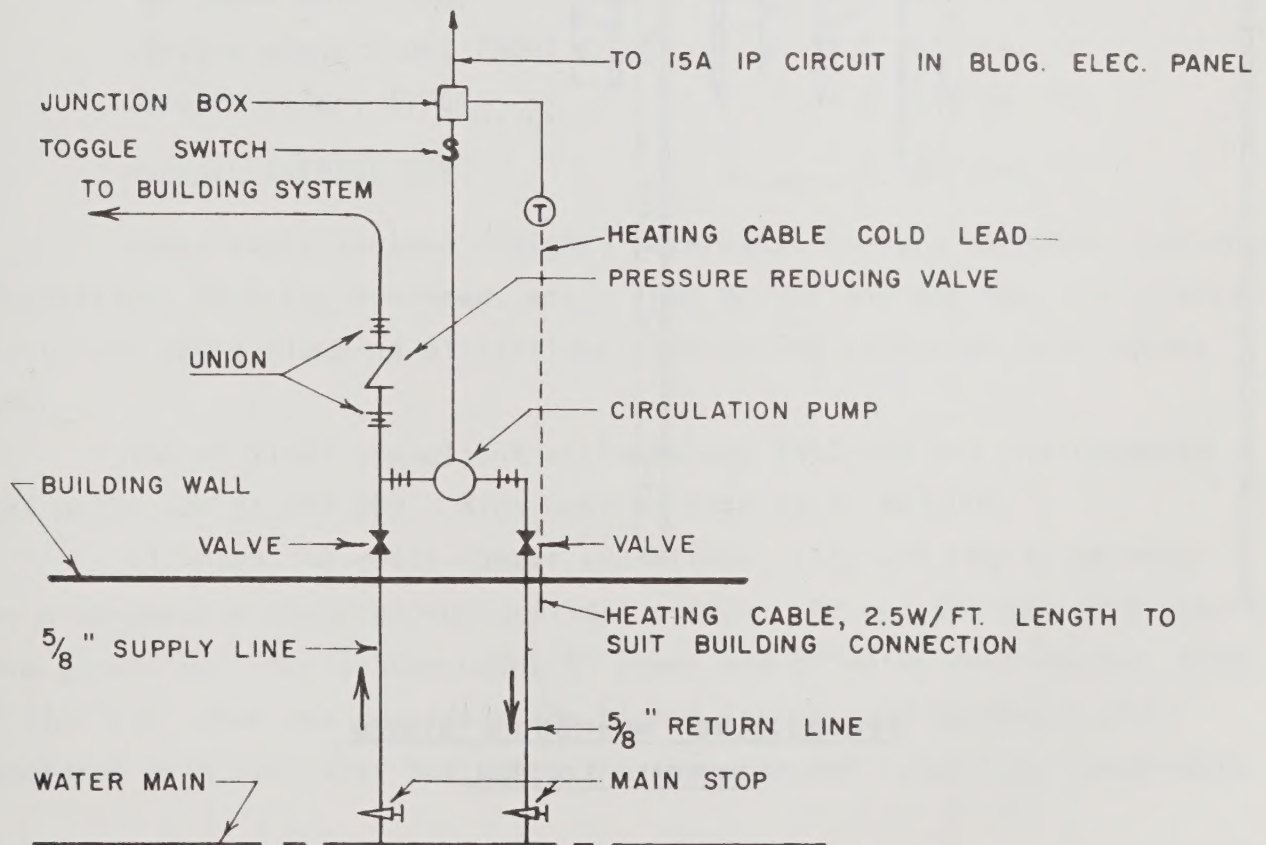
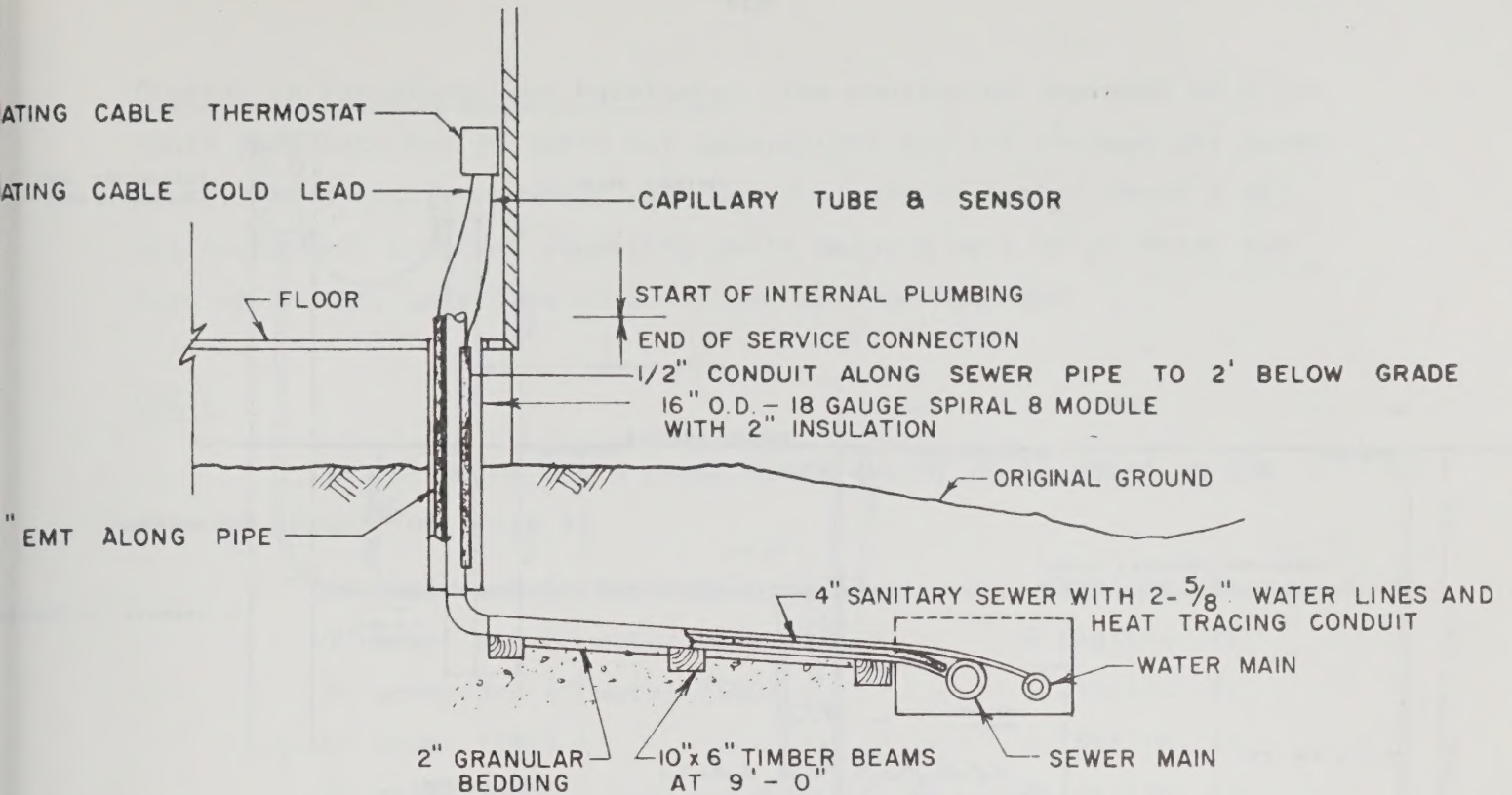
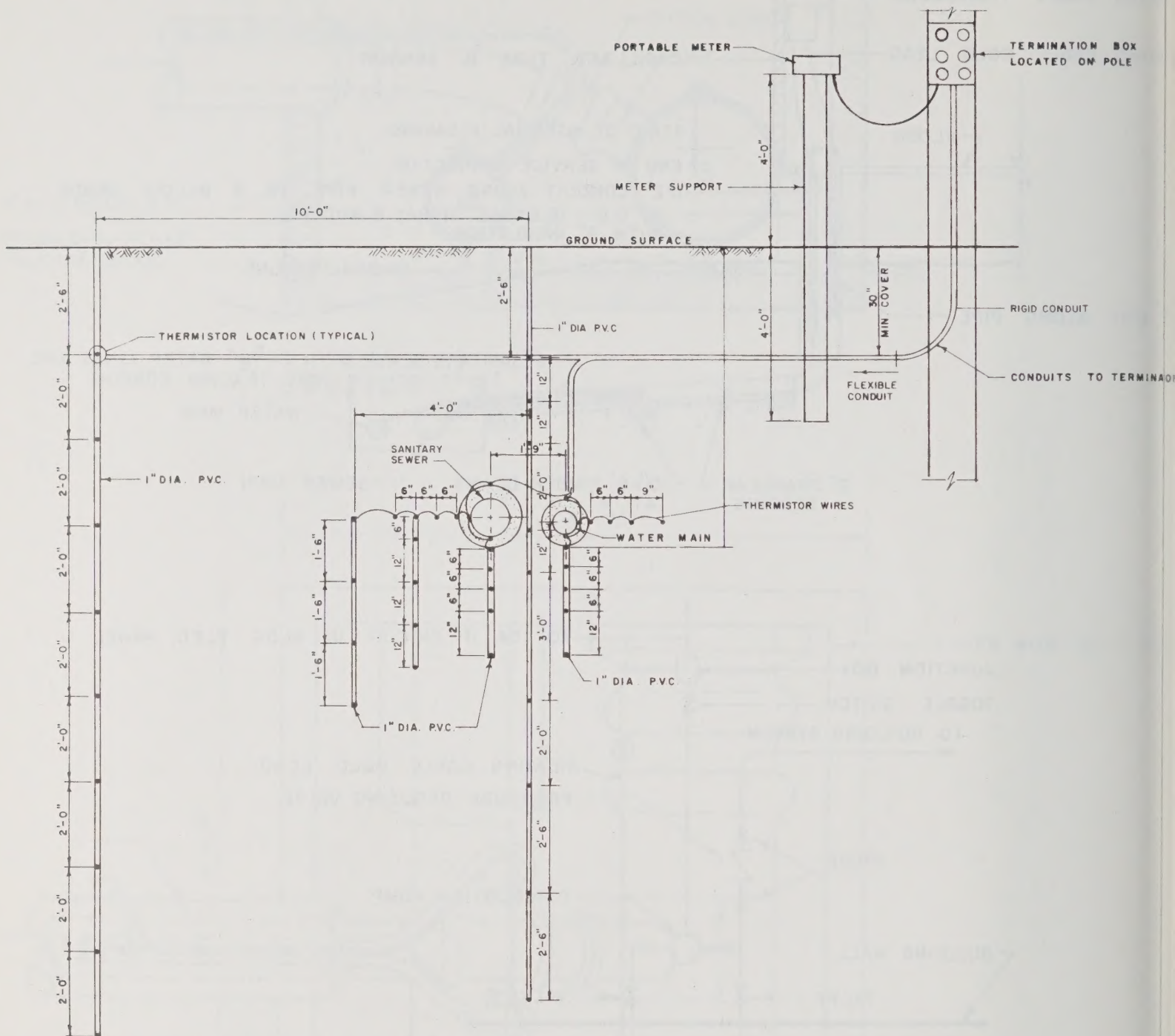


FIGURE 11. BUILDING SERVICE CONNECTION



TEMPERATURE MONITORING SYSTEM
TYPICAL SECTION

FIGURE 12. TEMPERATURE MONITORING SYSTEM

Digging in Permafrost and Machinery: The contractor depended on a one cubic yard back hoe to carry out excavations and cut through the permafrost. As a result he would wear out two sets of bucket teeth a day. Any mechanical problems requiring parts meant a wait of at least two days while they were ordered and flown up from Montreal.

COSTS

The following are a rough break out of costs based on the awarded tender for Phase I:

10" sewer and 6" force main (535)	\$229/lin. ft
10" sewer and 6" water main (835)	\$ 229/lin. ft
8" sewer and 4" water (500)	\$ 219/lin. ft
10" sewer (760)	\$ 180/lin. ft
8" sewer (500)	\$ 166/lin. ft
6" water main (370)	\$ 164/lin. ft
4" water main (370)	\$ 162/lin. ft
Service connections (900)	\$ 163/lin. ft
Service risers (170)	\$ 164/lin. ft
OVERALL AVERAGE COST	\$ 190/lin. ft

Above costs include freight, materials, labour, manholes, hydrants, modilization, profits, overhead, etc. They do not include the lift station or interior house plumbing alterations, monitoring system or contingency funds.

The original consultant estimate was \$650,000 and the tendered total price was \$1,208,000. Bids went as high as \$3,400,000.

Although the costs appear exorbitant, they are really no more than a comparable above ground utilidor system. Prices for the 1975 Inuvik above ground utilidor system using 8" sewer and 8" water runs approx. \$200 per lin. ft. When one considers the higher freight and overhead costs associated with Frobisher Bay, then the costs appear relatively comparable.

PHASE II

In Phase II the following changes are being considered:

The lift station will be of the packaged variety totally underground except for the access manhole. The pumps will therefore be submersible as opposed to the first lift station where the pumps are surface mounted suction pumps. It is expected this will decrease the cost of the lift station by a very significant amount as well as reduce construction installation time.

The heat tapes in the main lines as well as the service connections are being looked at to see if they can be eliminated or modified to reduce the cost. In the service connections the heat tapes will be eliminated and the supply and return water lines will be energized if necessary to thaw out the lines. In the main lines with victaulic joints or tyton, EMT conduit was necessary as a carrier pipe for the heat tape. This meant that the conduit had to be curved smoothly over the joints to allow the heat tape to be pulled in. It is thought that both the heat tape and the conduit could be eliminated by energizing the pipe if and when required from MH to MH. This would reduce initial capital cost by as much as \$20/ft.

Finally the present method of insulating the manholes is not considered as reliable as it could be. Rigid urethane breaks down when subject to continuous exposure to water not to mention the periodic freeze thaw actions. Phase I manhole insulation was not protected at the earth-insulation interface. In Phase II it is hoped either to spray the exterior of the insulation with a flexible water-proof membrane or apply the insulation to the inside of the manhole and spray again for further protection.

CONCLUSION

In conclusion, the Frobisher Bay utilidor is far from a proven successful northern utility delivery system. However, it is considered that the objectives set out for the system will be achieved in time.

These objectives are:

- to provide water and sewer services in a permafrost barren land area that will not deter from the natural surroundings;

- to provide a sewer and water system that has a sufficient life span to make it an economical alternative to other forms of water and sewer delivery; and,
- to provide a good standard water and sewer system that will require a minimum amount of maintenance and as well as minimal day to day operating problems.

Personally, I believe the Frobisher Bay System will meet the above objectives.

THE TOWN OF INUVIK, A CASE STUDY

by

E.I. Carefoot
Associated Engineering Services Ltd.
Edmonton, Alberta

INTRODUCTION

Inuvik was conceived in the early 1950's in an attempt to relocate Canada's largest northern settlement to a site with physical conditions that would permit a more economical development of a model northern town. How well the goals have been achieved is a matter of conjecture.

This paper is an attempt to provide the early conceptual ideas, along with sufficient description of established facilities at the new site at the present time, to permit one to make his own judgement as to the degree of success. If all is not as you would like it in 1976, remember that it is easy to sit in a comfortable 737 Jet and be critical during the two hours and forty minute trip back to your southern home.

BACKGROUND INFORMATION

Aklavik prior to the inception of Inuvik was the most important settlement in northwestern Canada. It was on a main navigation channel of the Mackenzie River. Water transportation was available almost entirely unrestricted to Fort Smith, which lies on the 60th parallel. Rapids at Fort Fitzgerald, over a 12 mile strip, were the only real impediment to water transportation between the Arctic Ocean and Fort McMurray. Prior to the Mackenzie Highway to Hay River, this water transportation route was linked to Edmonton by rail from Waterways on the Clearwater River, a short distance from its confluence with the Athabasca River.

By 1950 Aklavik had assumed some considerable importance with a permanent population of 400 and a surrounding population of 2,000. Located there was the administration centre of the Department of Northern Affairs and Natural Resources, a seven man R.C.M.P. detachment, a forest ranger, a forest and wildlife officer, two medical doctors employed by Indian Health Services, an Indian agent, a Royal Canadian Navy Station, Royal Canadian Corp. of Signals, a Department of Transport Meteorological and Radiosonde Station, a Roman Catholic and Anglican mission, a 50-bed Roman

Catholic Hospital, a 120 bed Anglican Hospital, a 120 student residential school, three stores, a post office, CPA office, and many residential buildings.

Several new buildings were to be constructed in 1954 and 1955 summer seasons. These were to include a 80 bed R.C. hospital, a 10 room government operated day school, a principal's residence, an 8 apartment teacherage, a 25 man naval barracks, a mammalogist laboratory and a number of smaller buildings, garages, etc. and an extension to the Anglican residential school.

In order to accommodate the rather extensive growth, the Department of National Health and Welfare carried out an intensive investigation into the short and long range sanitation and sanitation facilities of the site.

The conclusion reached by the investigation was that there were many real problems that would have to be surmounted before a reasonable semblance of sanitary conditions would be possible. In order to provide proper services, a year-round water and sewer system was recommended.

In an extensive report dated August 31, 1953, Mr. J.W. Grainge, an Engineer with the Department of National Health and Welfare, suggested that consideration be given to the selection of a new townsite.

In order to best describe the problems, an extract from the report is as follows:

"Alternative Townsite Discussion:

If the recommendations for year-round water and sewage systems are not accepted, it is suggested that consideration be given to reducing the size of the settlement. This could be effected by locating some of the buildings which are still in the planning stage and, also some of those that must be replaced. It is understood that an airport in the vicinity is needed, and if these buildings were located near a suitable airport site, no doubt they would serve as a nucleus for the Department of Transport townsite.

The location of the settlement of Aklavik is unfortunate from many points of view. The permeability of the silt soil is extremely low so that even small rains make the roads very muddy. Four wheel drive vehicles are a necessity in summer. Because the silt soil is also unstable, the roads are continually slumping into ditches, aggravating still further the problem of the drainage of this flat area, and increasing the cost of road maintenance. Building construction and maintenance costs are particularly high, due in a large part to permafrost foundation difficulties, as well as to the cost of hauling sand and gravel by boat from Arctic Red River about 100 miles away (\$25.00 per yard).

It is suggested that consideration be given to sites on the mainland which is ten miles west. It is understood that one suitable site for a townsite and airport is a shale plateau on the west band of the Husky Channel, 12 miles from Aklavik. The shale would provide a solid foundation for buildings and suitable material for road and airport runway construction. If an airport were located here, cargoes might be transhipped to Aklavik by boat or "Norseman" pontoon plane as is now done at Port Radium."

It is interesting to note that here was a proposal to reduce or limit the size of Aklavik. The decision of the Government of Canada, as best I am able to determine from reports made in 1953, was to move the entire settlement to a new site.

FACTORS CONTRIBUTING TO THE MOVE

The Mackenzie Delta is a permafrost or perenially frozen area to several hundred feet depth, except under lakes and major stream beds. The soil at Aklavik is a fine grained organic silt with a very high moisture content. Investigation shows that about 60% by volume of the fine grained soil is ice. When the natural vegetation is stripped and heated buildings placed, ground subsidence or loss of stability occurs.

The settlement site is very flat and river flooding in the past had inundated all but small local areas of the townsite. Because of the presence of permafrost and low stability material when thawed, construction and maintenance of proper drainage ditching is next to impossible.

Under these conditions, it was considered that laying of water and sewer mains would be both expensive and risky and would create greater problems. With our present day pipe materials and insulation and greater knowledge of the problems, the construction of utilities would have been a little more practical.

In order to continue to exist as a viable townsite in the far north, it was essential that a year-round airport be available. Attempts were made to construct an airport, but the soil conditions and lack of stable granular material made it impossible.

In reviewing files and reports on Aklavik pertaining to that period, the predominant theme was the lack of suitable sanitary facilities and the extremely difficult and expensive job it would have been to provide services. Needless to say, this was one of the prime considerations and a major requirement of a new site.

CRITERIA FOR A NEW SITE

In order to best set out the criteria for a new site, I shall use the criteria as noted by Mr. C.L. Merrel, Mr. J.A. Pihlainen and Mr. R.F. Legett in a paper presented to the Ottawa branch of the Engineering Institute of Canada on September 18, 1965. This paper was later published by the National Research Council as Technical Paper #89-NRC 5573.

The essential factors for any new townsite were determined as follows:

- (a) the site must be suitable from the economic and social points of views;
- (b) the site should be suitable for the installation of permanent sewer and water systems, building foundations, and roads;
- (c) the site should be on, or very close to, a good navigation channel within the delta;
- (d) the site must have reasonably close to it a suitable area for the construction of a permanent first-class air field; and,
- (e) there should be, within economical distance, a suitable public water supply.

The following were regarded as highly desirable features but were not quite so important as those already listed:

- (f) the site should provide for economical and convenient disposal of sewerage;
- (g) it would be convenient if there were a good supply of gravel and sand nearby for building purposes; and,
- (h) from the navigation point of view it would be desirable if the wharf facilities could be used as a trans-shipment point for freight from river vessels to sea-going vessels which could sail out into the Arctic Ocean.

Finally, the following three factors had to be kept in view as desirable but in no way essential:

- (i) availability of a good wood supply;

- (j) availability of coal for heating purposes; and,
- (k) if possible, availability of water power which could be used for the generation of power for public supply.

SITE INVESTIGATION AND CONCLUSIONS

With the objectives in mind, an investigation team was assembled in January 1954 and was to be in the field by March 15.

An eight man team was raised under the leadership of C.L. Merrill and included:

K.C. Berry.....	Department of Public Works
R.J.E. Brown.....	National Research Council (D.B.R.)
G.H. Johnston.....	National Research Council (D.B.R.)
J.A. Pihlainen.....	National Research Council (D.B.R.)
J.K. Fraser.....	Department of Mines and Technical Surveys (Geographical Branch)
E.J. Garrett.....	Department of Transport
J.W. Grainge.....	Department of National Health and Welfare
C.L. Merrill (Leader).....	Department of Northern Affairs and National Resources

"Ex-officio" advisory members were provided by the Royal Canadian Navy, Canadian Army Signals, and Royal Canadian Mounted Police.

An Aklavik Advisory Committee of local trappers, traders, Eskimo, Indian Mission, Territorial Government and Northern Affairs representatives provided local knowledge.

After a photo investigation, aerial reconnaissance and much hard work on the ground, the findings pointed to East Three as the most desirable site for the New Aklavik. After further site visitation and consultation the Federal Cabinet, upon recommendation of the Minister of Northern Affairs, on November 18, 1954 declared that the Town of Aklavik should be moved to the new site.

By proclamation in July 1958, the area known since 1954 as East Three or (New) Aklavik was named "Inuvik", Eskimo for "the place of man".

With this background we will proceed in to the main theme.

EXISTING UTILITIES

Water Supply

The water supply for the Town is obtained from three sources, Hidden Lake, Mackenzie River, and Lake "B".

Hidden Lake acts as a raw water supply reservoir and is used as a reserve to be utilized in spring and fall season during freezing-in period of the Mackenzie and during the spring breakup period. The lake's natural replenishment is from snow and rain off a limited basin area and is calculated to be in the order of 7 million gallons. The immediately usable storage volume of the lake under maximum ice conditions is in the order of 12 million gallons. Assuming a breakup period of 2-1/2 to 4 weeks, the demand on Hidden Lake could be 6 to 10 million gallons. Obviously other sources must be available reserving Hidden Lake at a full supply situation in readiness for the spring breakup.

During the winter when the Mackenzie River is clear, water is supplied from the river by a pump located on the ice.

In 1973 a three mile water supply line was constructed to a large lake, termed Lake "B". The pipeline is a 6- and 8-inch steel line uninsulated, laid on the tundra. As soon as spring weather permits, water is pumped to Hidden Lake to replenish it and supply the daily summer requirements.

Water supply from Hidden Lake is filtered with a microstrainer followed by the addition of chlorination and fluoridation treatment.

Water pumped directly from the river receives only fluoridation and chlorination.

Needless to say the original system is outgrown and measures are being taken to upgrade the water supply system.

The existing 90,000 gallon treated water storage will be phased out with the completion of a 0.5 million gallon reservoir in 1976. The steel tank was erected in 1975 and remains only to be insulated and connected into the system.

The microstrainer in the treatment plant is overloaded and provides inadequate filtration. It is also undesirable to continue pumping unfiltered Mackenzie River water directly into the system.

To correct these deficiencies a new filtration plant is presently in the design stage. This plant will be located adjacent to the river, and will be capable of being extended to provide complete treatment of river water.

Sewage System

The Town of Inuvik is serviced by what is essentially a gravity sewer system. One small lift station serving a local area is located in the Hostel Building on Block 17 and the other is on the outfall line. The second one is a booster pump and will be eliminated this year with the commissioning of a new 12-inch and 14-inch outfall. Sewage is disposed of in a lagoon at the northerly end of the Town. The lagoon was constructed by placing an impounding dyke around an existing small lake. The level of water in the lagoon is controlled by a weir structure, with the overflow of treated effluent being returned to the Mackenzie River about a half mile downstream.

The Utilidor

Having reviewed, by general description, the water distribution and sewage collection and disposal system, it is now in order to discuss the conveyance system and the utilidor. This is the main difference between utilities systems of Inuvik and the south.

The piping of freezable liquids in cold weather regions requires special techniques and equipment.

Permafrost in the Inuvik area contains moisture in the 50% or greater range and in some places contains massive ice. It is extremely difficult to excavate in either summer or winter and when thawed becomes a flowing quagmire with very little stability. It is, therefore, considered impractical to install underground lines. There are some areas in Inuvik that may be, where underlain with good gravel, and with proper soils investigation and design, suitable for the installation of an underground system. Heat lost from a pipe would thaw the ground and upon refreezing could cause frost heaving and differential movement, and possibly cause structural failure of the piping system.

Thawing and repairing lines would be very difficult and time consuming, especially under the conditions of extreme temperatures that

are prevalent. Stoppage of flow in the pipes must be kept to an absolute minimum as both the mains and services freeze very rapidly under no flow conditions.

For these reasons, the water and sewer pipes are installed above ground in Inuvik. The system, called a utilidor, uses an insulated enclosure that houses one or more pipes, usually a water and sewer line, and in the case of the original installation, high temperature supply and return lines. The high temperature water is primarily to provide the connected buildings with hot water for heating purposes, but has one great side benefit in that it prevents freezing of the other lines in the utilidor.

It is not the intention here to go into all details of the utilidor system as it exists in Inuvik, but to touch on the salient features of some designs. For those people unfamiliar with the utilidor or wishing to go into detail, a report entitled "Comparison of Utilidors in N.W.T." by A.F. Leith and G.W. Heinke, published by the University of Toronto as 70-60 is recommended.

The first utilidors built in Inuvik were of very substantial design, with steel frame and metal cladding, supported on a pile foundation. This was a large utilidor, approximately 4'x4', and contained water pipe, sewer pipe, and high temperature water and return lines, four pipes in all. It is a rather expensive type of utilidor costing about \$230 per lineal foot in 1957. This design is only used when high temperature water lines are required. Except for damage to the light weight corrugated metal roof by foot traffic, the utilidor has stood up well.

Different types of utilidors have been constructed over the subsequent years, incorporating a number of details aimed at reducing the costs.

The components of a utilidor are: foundation or supports, structural enclosure, exterior cladding, insulation, and piping. About eight different types of utilidors using various combinations of materials have been used, designs have been modified to reflect the functions of the utilidor.

(Reference Report entitled "Water and Sewage System Analyses, Town of Inuvik, N.W.T." prepared for Northern Canada Power Commission by AESL, 1973).

The greatest problem to be contended with in the utilidor system operation is the prevention of freezing of the lines. They are much more vulnerable to freezing than in a buried system, being exposed to ambient temperatures of as low as -54°C (-65°F). Both water and sewer lines have frozen on occasion.

Some of the probable causes of freeze-up are:

- (a) failure of the auxiliary heating system or circulation pump;
- (b) insulation becomes damp or wet, reducing its "k" value, water absorbent insulators such as zonolite should not be used;
- (c) inadequate insulation;
- (d) access hatches left open, or non-authorized openings made for service connection installation; and,
- (e) build-up of sludge in sewer, allowing ponding and freezing of sewage to commence.

One principle to be kept in mind is that insulation alone will not prevent freezing. If heat loss is greater than heat supply, a freezing condition is created. Insulation merely helps reduce heat loss and maintain a positive heat balance.

Potential cold spots such as metal fittings should be avoided, or well protected. Normally, if circulation is maintained, freezing will not occur.

The cost of servicing property is very high. Current costs of wooden structured utilidors is in the order of \$170 - \$200 dollars per lineal foot as compared to \$40 dollars for a buried water and sewer system in the provinces.

The high profile of the utilidor causes considerable inconvenience and expense to the street system, requiring expensive and inconveniently high overpasses. The continuous nature of the structure forms a physical barrier. Service connections, being similar but smaller, tend to divide the rear yard into two separate areas. This does not appear to be as great a problem as one would expect because of the lesser use made of back yards. Perhaps this is because of the barrier, but is is also partly because of the soil and climatic conditions.

PLANNING: ANTICIPATION vs REALIZATION

Looking back from 1976 to 1954 it is interesting to recall the "guide for requirements for a new site" and note to what extent the new site fulfills the requirements.

The Site Must be Suitable From The Economic And Social Point Of View

The original population visualized for the community was established at a maximum figure of 1300 while the original Town plan to be served by a utilidor for heat, water and sewer, had a capacity for 2000 persons. The provision of all the governmental services, in terms of physical layout and utilities, attracted considerable migration from the Delta area, in addition to persons from the south involved in activities other than those of Government. Very soon the original utility system was outgrown and the new, and not anticipated population located mainly in the western portion of the Town. This situation resulted in inequities in terms of urban facilities, amenities and services. In addition to differences in standards, it has even produced considerable social and economic divisions within the community, and considerable strain on the newly emerging municipality of Inuvik attempting to place all of its residents under an equal standard of services.

Programs of servicing of the west end have been undertaken and the differences between the two parts of the Town have been reduced to a considerable extent. The oil and gas exploration in the Delta and Arctic Islands was, by necessity, based in the Town of Inuvik, thus putting further strain on the facilities.

In addition to the Government and oil industry generated employment, the Canadian Armed Forces expanded their personnel based in Inuvik. At this particular point, substandard housing, overcrowding and lack of services became even more acute. The permanent and transient population of Inuvik has now reached the level of 4000 persons.

While the Governmental agencies and the major industrial corporations engaged in various aspects of oil and gas exploration are able to meet the high cost of housing and subsidize the same for their own employees, the native population and the migrants from the south do not have the same financial resources or backing. Consequently, the housing problem

became not only an issue of opening new areas and providing the services, but also a very serious social and economic problem which creates inequities and frustrates the normal development of the community. (Makale, Holloway & AESL, 1973)

The Site Must Be Suitable for the Installation of a Permanent Sewer and Water System, Building Foundations and Roads

Suitability of the site for water, sewer and roads is a matter of relativity. The survey team were aware that the new town would still have to be founded on permafrost as it was impossible to find any site in the delta area that was not underlain by perennially frozen ground. The glacial nature of the soils with its fluvioglacial gravels and stony glacial tills, with various amounts of fine grained material, has provided a much better area than available at Aklavik. The site has not been considered suitable for the installation of underground utilities so that a rather expensive above ground utilidor system has been developed.

The construction of roads has been proceeded with. Where good engineering, using the principles and procedures as developed for permafrost areas, is followed, few problems are encountered. The roads are expensive, but not more so than would have been at Aklavik, because of the availability of granular material. To prevent degradation of the permafrost with resulting subsidence, a minimum depth of fill of over four feet must be maintained.

Technology available in 1954 with some modifications for site conditions has allowed the buildings to be constructed with a minimum of foundation problems. The writer is not aware of any foundation problems where sound engineering principles, as developed for permafrost terrain, have been adhered to. On the other hand there are numerous cases of failure due to ignorance of the principles or knowingly ignoring them.

The Site Should Be on or Very Close to a Good Navigation Channel

The condition is fairly well fulfilled, with Inuvik being located on the east channel of the Mackenzie River, with water of sufficient depth to provide draught for craft able to navigate the rest of the Mackenzie River system from Hay River to the Arctic. Being a side channel, it is not subject to quite the same problems as the main channel. Occasional

blockage of the channel by ice during breakup causes flooding of the docking facilities.

The Site Must Be Reasonably Close to a Suitable Area for the Construction of a Permanent First Class Airfield

This condition was met with a paved airstrip being located approximately seven miles from the Town. Again technology has permitted the construction of a satisfactory paved runway and servicing buildings with little problem due to permafrost terrain.

There Should Be, within Economical Distance, a Suitable Public Water Supply

As described previously, the townsite is supplied by water from three sources. Quoting early 1955 reports on water supply:

"The closest lake which might be considered is Hidden Lake. Its winter storage has been estimated at 6 million gallons, allowing for 6 feet of ice. This is not more than two months of storage for the ultimate town of five thousand, which is not felt to be adequate to get the town through the winter."

Next considered was the closest lake requiring more than two miles of pipeline. This was felt to be more expensive than the cost of developing an intake and treatment plant on the Mackenzie River. The Mackenzie River was considered a positive and dependable source, with the advantage that it would be close to the central heating plant and other services. Maintenance and operation would be reduced and it was considered no more expensive than obtaining water from the lake.

This alternative was pursued to the extent of the production of drawings illustrating intake and treatment plant for chemically treated, filtered and chlorinated water, as late as February 1956.

The assessment of water supply sources as determined at the time is still valid. However, two things have happened to require changes. Firstly the 50 gallon per capita per day consumption figure used as a design basis is vastly exceeded. Current records show a consumption of over 100 imperial gallons per day. Secondly, the current population is about 4,000 with a population of 7,000 expected to be reached by 1986. Long range planning presently is for a townsite of 10,000 population.

Design is under way on a treatment plant capable ultimately of treating Mackenzie River water, with the plant to be located adjacent to the river, in the proximity of the power plant as originally planned.

The Site Should Provide for Economical and Convenient Disposal of Sewage

Duck Lake was considered to be a suitable disposal site for untreated sewage. It was thought that there was sufficient algae growth in the lake to provide aeration of the sewage so that the odour would not be objectionable in the Town 1,000 feet away.

A sewage lagoon was developed at the northerly end of the Town by constructing a berm around the three low sides, isolating the area from the Mackenzie River. The water depth is controllable by a weir.

Over the years the Town has expanded toward the lagoon such that the nearest house is about 500 feet from the lagoon. An industrial subdivision has been surveyed paralleling the one side.

With an irregular bottom and varying depths, there is a general collection of sludge and debris contributing to odours, fly breeding and general unsightliness.

Summer tests conducted in 1971 show a lagoon effluent BOD loading of 40 mg/l, representing a reduction of 84%. There is need for either major improvements to the existing lagoon, relocation to a new site or construction of a treatment plant.

(Reference: "Evaluation of a Sewage Lagoon at Inuvik, N.W.T." by Nels A. Jacobsen B.A. Sc., University of Waterloo, 1972).

It Would Be Convenient if There Were a Good Supply of Gravel and Sand Nearby for Building Purposes

From our present day knowledge of the townsite and its future growth potential, the supply of gravel and sand is most likely to be the major deficiency of the site. Development of roads and land for building purposes is dependent upon vast volumes of granular fill being readily available at reasonable cost. Had the ultimate growth of the Town been around the 5,000 population figure, the gravel supply would not have been critical. However with its population presently at the 4,000 level, and with projection to 7,000 in the not too distant future, this has become one of the most critical and expensive items of development. Early deve-

lopment was carried out on the choice land which was thinly moss covered gravel. This area has now been all utilized, forcing growth onto deep muskeg, high ice terrain underlain with silts and till containing massive ice in some locations.

The large gravel deposits located at the south entrance to the Town are now practically depleted. Sand supply is non-existent in a near radius to the Town. An extensive clay shale pit has been opened about four miles from Town and is the major source of low grade fill.

Exposed dolomite bedrock outcrop beyond the airport could form a supply source of high quality crushed rock. This source is 10 miles away and production and crushing costs result in very expensive material. A virtually unlimited supply of sand and gravel is available beyond Reindeer Station with a haul of 35 miles over winter road.

It Would Be Desirable if Wharf Facilities Could Be Used for Trans-Shipments Point for Freight from River To Sea-Going Vessels for the Arctic Ocean

This condition is not met partly because of the depth of the river at this location but more so because of the shallow draught at the mouth of the numerous channels where they empty into the Arctic Ocean. As a result, the harbour at Tuktoyaktuk provides the transshipment facilities.

Factors kept in view, but in no way essential:

Availability of Good Wood Supply

Availability of Coal For Heating Purposes

Availability of Water Power which Could Be Used for Generation of Power for Public Supply

These three items, wood, coal and water power, pertain mainly to a fuel supply source and are not available at or near the site. Fuel source for heating and power generation is diesel or bunker oil, delivered from Norman Wells or Alberta sources.

These are both major and expensive items in Inuvik, contributing largely to the high cost of living.

A successful search for oil and gas in the Northwest Territories, and particularly in the Mackenzie Delta and Beaufort Sea could provide a plentiful supply of fuel, at a relatively low cost. Substantial reserves

of natural gas have been proven and should be available to the Town as soon as gas plants and pipelines are constructed to prepare and transport the fuel.

With this, I will leave the audience to be the judge of how well the hopes and aspirations of the Committee of 1954 are being met in 1976.

INUVIK - ITS FUTURE

Every day we are confronted with staggering numbers like the billions and trillions of cubic feet of natural gas reserves, and the million of potential barrels of oil. We hear such names as Taglu, Parsons Lake, Pan Arctic's Ben Horn, and its Hecla with tests of 240 mmcf/day, and offshore potential. We hear of 36-inch and 48-inch pipelines costing a staggering 10 billion dollars.

What does it all mean? Does the average person understand the implications of all this? To go one step further, does ANYONE really comprehend the ramifications of such development?

What will this do to Inuvik? What can we expect by 1990 or at the turn of the century? Will Inuvik be a metropolis of 100,000, the glittering hub of Northern Canada flushed with boom town economy, or will it be a 5,000 population town of single family dwellings, one-storey buildings and dusty streets, struggling to maintain itself and get its feet out of the dust and mud, dying with the phasing out of another oil centre?

A "fearless" prediction of a population of Inuvik in 1999 is 8,000 - 10,000 people. Population projections indicate that a high intensity petro-chemical activity could result in a population of 6,700 by 1985. Why such a minuscule growth in an area of such high intensity of development? Perhaps there is the attitude of the short-run phenomenon, a place of pure plunder, a place to make a quick stake and get out, a place of hardships and sacrifices to be undergone until one accumulates enough to live satisfactorily somewhere else. Only a few people have faith enough to invest their time and money in making permanent improvements. Until this attitude changes there is little prospect of continuity or permanence in the population or the economy.

Can Inuvik grow to a population of 10,000 and if so, in what direction and at what cost?

A population growth to 7,000 will utilize all the available useful land in the townsite if the present trend of low density, single family housing is followed. Tremendous quantities of granular material will be required to prepare the land for development. A recent study indicates 3 million cubic yards would be needed for residential development alone. With the cost of utilities escalating as they are, what is to be done to hold these costs?

One of the exciting ideas that comes into mind when thinking of northern housing and development is the single enormous building complex or a series of covered domes. The physical convenience of such a town would be great and would tend to be economical in heating and maintenance. The greatest difficulty would probably be of social and psychological nature as it would tend to be a gigantic institute. Negative experience has been reported from northern encampments where people have been able to live without contact with the outside elements.

Due to the fascination that engineers and architects have for such structures, it is necessary to warn against such science-fiction aspects of the concept and the over exaggeration of their importance.

A much more practical form of shelter is required. Economics will force the use of multiple housing. Why not multiplex or three-storey walk-up housing built to a high standard? Connect them to the central core or assembly area with covered walkways.

To total indoor greenhouse living, I say no. If this is what the southern transplant would like, or needs, he should not be there.

With the development of natural resources, the role of the north changes. Instead of hunters and traders, the north must attract engineers and technicians and their wives and families, people with special knowledge and capacities.

In the great rush to develop the resources, we must not forget the people who were there before the "industrial revolution" and will be there long after.

Man in his ingenuity has invented many ways to allow his survival. As his inventiveness and creativity increased, he has created conditions of convenience, comfort and pleasure.

Hopefully, the resulting buildings and towns and amenities will serve the needs of all the people.

REFERENCES

1. "The New Aklavik: Search For The Site" by C.L. Merrill, J.A. Pihlainen and R.F. Legget. NRC 5573, 1960.
2. "Above Ground Utilidor Piping Systems For Cold Weather Regions" by C.R. Hoffman, Naval Civil Engineering Laboratory - Technical Report - R-734, 1971.
3. "Comparision Of Utilidors In Inuvik, NWT" by A.F. Leitch and G.W. Heinke, University of Toronto, Department of Civil Engineering, 1970.
4. "Inuvik, NWT Engineering Site Information" by J.A. Pihlainen, NRC 6757, 1962.
5. "Evaluation of a Sewage Lagoon at Inuvik, NWT" by G.W. Heinke, H.K. Miyamoto and N.A. Jacobsen, University of Toronto, Department of Civil Engineering, 1972.
6. "Engineering Study, Inuvik, NWT" by Department of Public Works of Canada, Development Engineering Branch, 1965.
7. "Capital Budgeting Program for the Town of Inuvik, NWT" by Makale, Holloway and Associates, Associated Engineering Services Ltd., 1973.
8. "Water and Sewage System Analysis, Town Of Inuvik, NWT" by Associated Engineering Services Ltd., 1973.
9. "Architecture and Town Planning in the North" by R. Erskine, reprinted in Northern Engineer, Volume I, No. 4, Fall 1969.

ACKNOWLEDGEMENTS

I would particularly like to acknowledge the valuable assistance of Mr. J.W. Grainge of the Federal Department of Health and Welfare, Medical Services Branch, and one of the original members of the 1954 survey team in providing me with first hand information of the early investigation of the townsite, and directing me to and making available sources of early correspondence and reports.

VACUUM SEWAGE COLLECTION IN THE ARCTIC

NOORVIK, ALASKA: A CASE STUDY

by

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INTRODUCTION

The water and sewer systems discussed here were constructed by the Indian Health Service with funds appropriated under Public Law 86-121, the Indian Sanitation Facilities Construction Act of 1959. The Indian Health Service is part of the Health Services Administration of the U.S. Department of Health, Education, and Welfare, and is responsible for improving the health of all Indians and Alaska Natives to the highest possible level. As part of this mission, the Sanitation Facilities Construction Branch of the Indian Health Service's Office of Environmental Health plans, designs and constructs sanitation facilities on Indian reservations and in Alaska Native Villages.

The construction of water and sewer systems in remote areas presents many problems. In arctic Alaska, these problems are compounded by the cold with its accompanying freezing problems and unique soil conditions. The remoteness results in long lead times for delivery of materials (many villages receive one barge shipment per year and have airstrips suitable only for small planes) and long delays waiting for parts when equipment breaks down. The climatic conditions often require that much of the excavation be done in frozen ground (in permafrost areas) which slows down construction and is extremely hard on equipment. Construction seasons are short and winters are long and cold. All of these problems, in addition to high labor costs, yield projects costing as much as four times the cost of a similar project on a reservation in the western United States.

This paper is devoted to a project under which complete water and sewer systems were constructed in the Eskimo village of Noorvik, Alaska. Noorvik is located in northwestern Alaska about 400 miles northwest of Fairbanks and 20 miles above the Arctic Circle.

The concept of the vacuum sewer system was developed by Liljendahl in 1959. The author first learned of the system in 1971 from a co-worker who attended a international arctic health conference in Oulo, Finland. More detailed information was subsequently obtained from the Environmental Systems Division of AB Electrolux in Stockholm, Sweden which manufactures the system. A thorough study of this information indicated that the vacuum system appeared to be practical for many arctic communities in which buried pipelines were not feasible because of sub-surface soil conditions. In communities such as these, piped sewer services has often required extensive pumping and the construction of costly utilidors on piling to maintain grades. The vacuum system eliminates both the pumping and rigid utilidors in that it can tolerate slight movement of pipes and, within limits, operate with changing and even reverse grades.

BASICS OF A VACUUM SEWER SYSTEM

The basic difference between the vacuum sewer system and the conventional gravity system is that the sewage is carried by air instead of water. A vacuum is maintained in the collection tank at the end of the sewer mains through the use of vacuum pumps, thus keeping the whole system under a constant vacuum. The system requires special toilets and special gray water valves which collect the wastes from conventional sinks, lavatories, bathtubs, and showers. The toilet is actuated by a push button which exposes the wastes in the bowl to the vacuum in the main by activating a discharge valve and at the same time activates a water valve which allows a small quantity of water to enter the toilet for cleaning purposes. The discharge valve closes shortly before the water valve, allowing a small quantity of water to remain in the toilet. The gray water valve operates under much the same principle although it is activated by the presence of water upstream from the valve through the use of a small pressure operated diaphragm. The diaphragm is mounted on a tee immediately upstream from the valve. As gray water is drained into the line and backs up into the tee, the diaphragm is activated and allows the vacuum in the main to open the discharge valve. The length of time the valve is open is controlled by a timer. This cycle will continue until no more gray water flows into the line and the fixture is empty.

The sewage in the main continues to move toward the vacuum source at the collection point as long as some point upstream from the sewage is open to the atmosphere, either through activation of a toilet or a gray water valve. Consequently, pockets of sewage in the line move in stages as upstream toilets or valves are operated. The pipe must be full in order for the air to carry plugs of sewage along the line. For this reason, low pockets are constructed into the system so that when the system is at rest, the liquid will flow to the low spots and ensure that the cross section is completely filled. (See Figure 1.) This prevents the air, which carried the sewage, from escaping over the top of the liquid in a partially filled pipe. After the sewage is collected in the vacuum tank it can be pumped to a treatment unit using conventional sewage pumps.

The vacuum sewer system has several advantages over a conventional gravity system since air and not water is the media of transport of sewage. Water is used only for cleansing of the toilet bowl, 1.2 liters per flush as opposed to approximately 5 gallons for conventional toilets. The system also eliminates the small but normal amount of exfiltration associated with a conventional sewer system in that any leaks in the sewer mains are inward since such the system is maintained under a constant vacuum. This feature greatly reduces the hazard of ground water pollution. Also, because water is not used in carrying the sewage, much smaller diameter pipes can be used for both sewer mains and house plumbing. An additional advantage which was mentioned earlier is the ability of the vacuum system to operate independent of grade. Because the system does not depend on gravity, the pipes can be laid completely flat and also with reverse grades within certain limits. For a buried system the cost of excavation can be greatly reduced. House plumbing can be simplified because collector pipes can be laid horizontally and smaller pipes can be used.

Although the Indian Health Service has had no prior experience with the vacuum system, the system and its components have been in use in Sweden, Mexico, and the Bahama Islands over the last 15 years. This experience has allowed the special components required for the system to be developed and tested fully to the point where they have a high degree of reliability and a long service life.

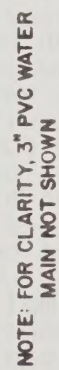


FIGURE 1. TYPICAL TRANSPORT POCKET

[illegible]

BACKGROUND OF THE WATER SYSTEM

The water system is basically a single main circulating system similar to many constructed by the Indian Health Service and others in arctic communities over the past several years. However, there is one important difference. Because the houses at Noorvik were constructed approximately 3 feet above the ground on wooden posts, it was possible to run the utilidors directly beneath the houses and to minimize the length of service lines required. Since water service lines have proven to be the weakest spot in other systems of this type, an additional feature was incorporated into the water system designed to minimize even further the length of the water services. This feature included looping the water main itself up through the floor of each house and back down into the utilidor, resulting in no service line at all and the house plumbing tapping directly into the water main. Pitorifices, which are normally used to provide circulation through water service lines on a single main circulating system, were not required, and the pumping needed to induce velocities high enough to cause circulation through the pitorifice service lines was not needed. Thus, circulation in the water main was reduced entirely to a question of thermal considerations.

SYSTEM DESIGN CRITERIA

Both the water and sewer systems were designed to serve 50 homes and were originally connected to 18 homes, several school buildings and a health clinic.

Because of the extremely cold climate, the above ground installation, and the resulting importance of thermal protection for the system, the water and sewer mains were installed side by side in the small utilidor. For this reason the Noorvik water and sewer systems cannot be completely separated and must be discussed together under a concept of total system design.

Due to the necessity of looping the circulating water system and the layout of the community, the utilidors were laid out in two loops, beginning and ending at the utility building. (See Figure 2.) The sewer lines were also looped within the utilidors and dead-ended at the utility building. Originally, the plan was to allow air to enter the sewer

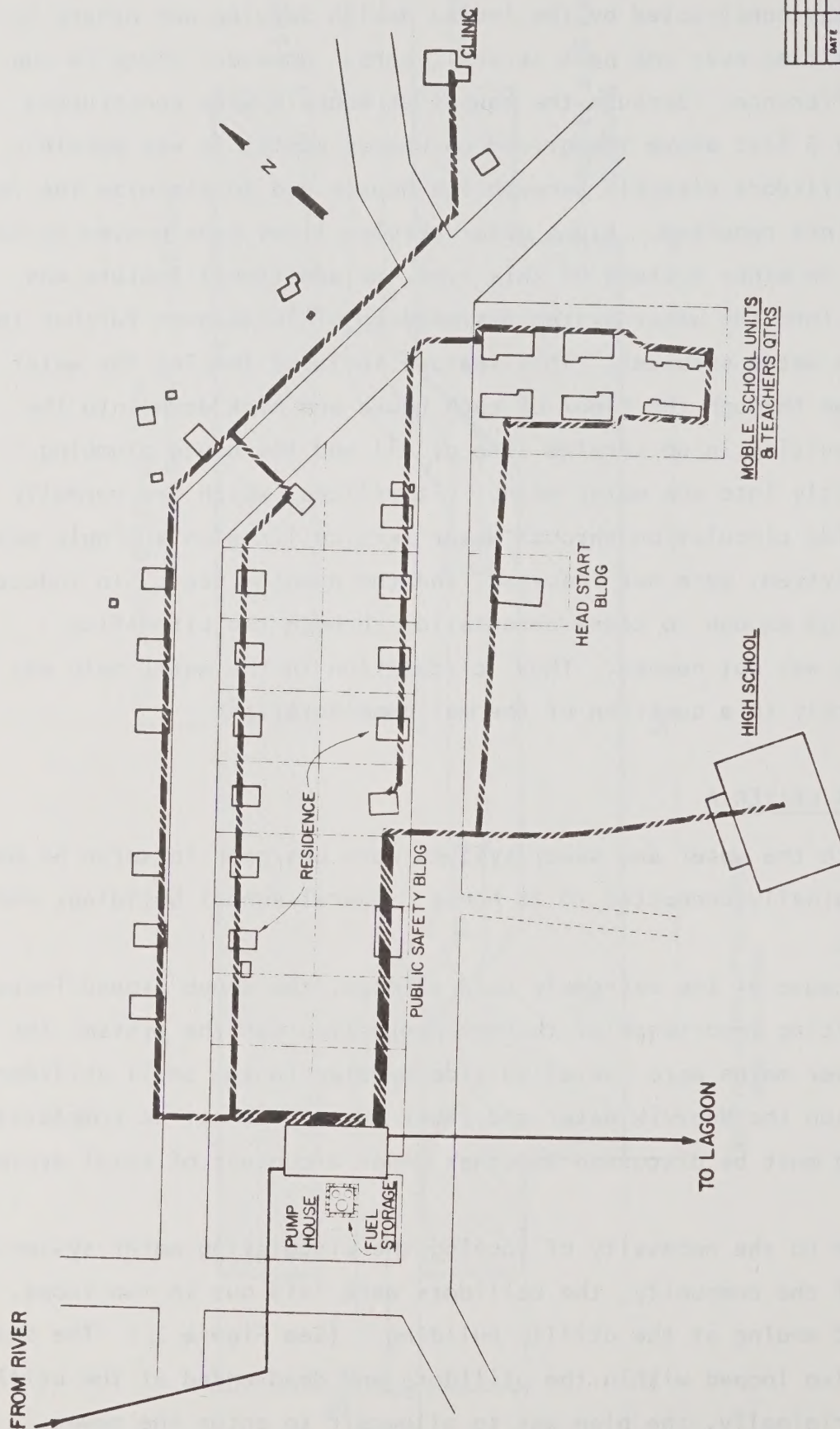


FIGURE 2. UTILIDOR LAYOUT

system through these dead end lines at timed intervals to insure movement of liquid in the sewers and to provide heat from the warm air. This process has not proved necessary for either reason.

The present construction of 20 new houses has required the addition of another utilidor loop. This was anticipated in the construction of the original system and the equipment was sized accordingly. An area was blocked out in the floor of the utility building to allow entrance of another utilidor and the piping was assembled for easy connection of the additional water and sewer lines. It now appears that an additional 10 new houses will be constructed in the future. Hopefully they will be located such that they can be connected to the new loop presently under construction.

The water and sewer mains along with the back-up heat tracing lines were placed in a common utilidor. The utilidor design was based on three main criteria: The first of these was insulation to minimize heat loss. This was accomplished through the inclusion of 4" of polyurethane insulation on the sides, top and bottom of the utilidor. Second, because the system would be above ground and exposed to possible damage from both pedestrian and vehicular traffic, structural considerations were very important. The basic utilidor design includes an 18 gauge steel exterior skin on the bottom and sides and 12 gauge steel on the top. These components have proven to give the strength required to minimize damage from exterior causes. In fact, many portions of the utilidor are used by the Noorvik residents in the summer as a walkway through the town. Finally, since the utilidor was to be installed above ground, its physical size was critical, in that it could provide barriers to the normal flow of traffic throughout the community. For this reason, the size was minimized, with the finished structure having overall dimensions of 16" wide by 12" high and placed directly on the ground surface. (See Figure 3) In many locations, 2" and 4" thick wood pads were used as needed to provide grading. The system was laid out to minimize road crossings and disruption of normal pedestrian traffic. Road crossings were constructed using two piece heavy weight aluminum culvert and 6" of soil cover. This design permits relatively easy access to the portion of the line beneath the road by removing the shallow cover and unbolting the top

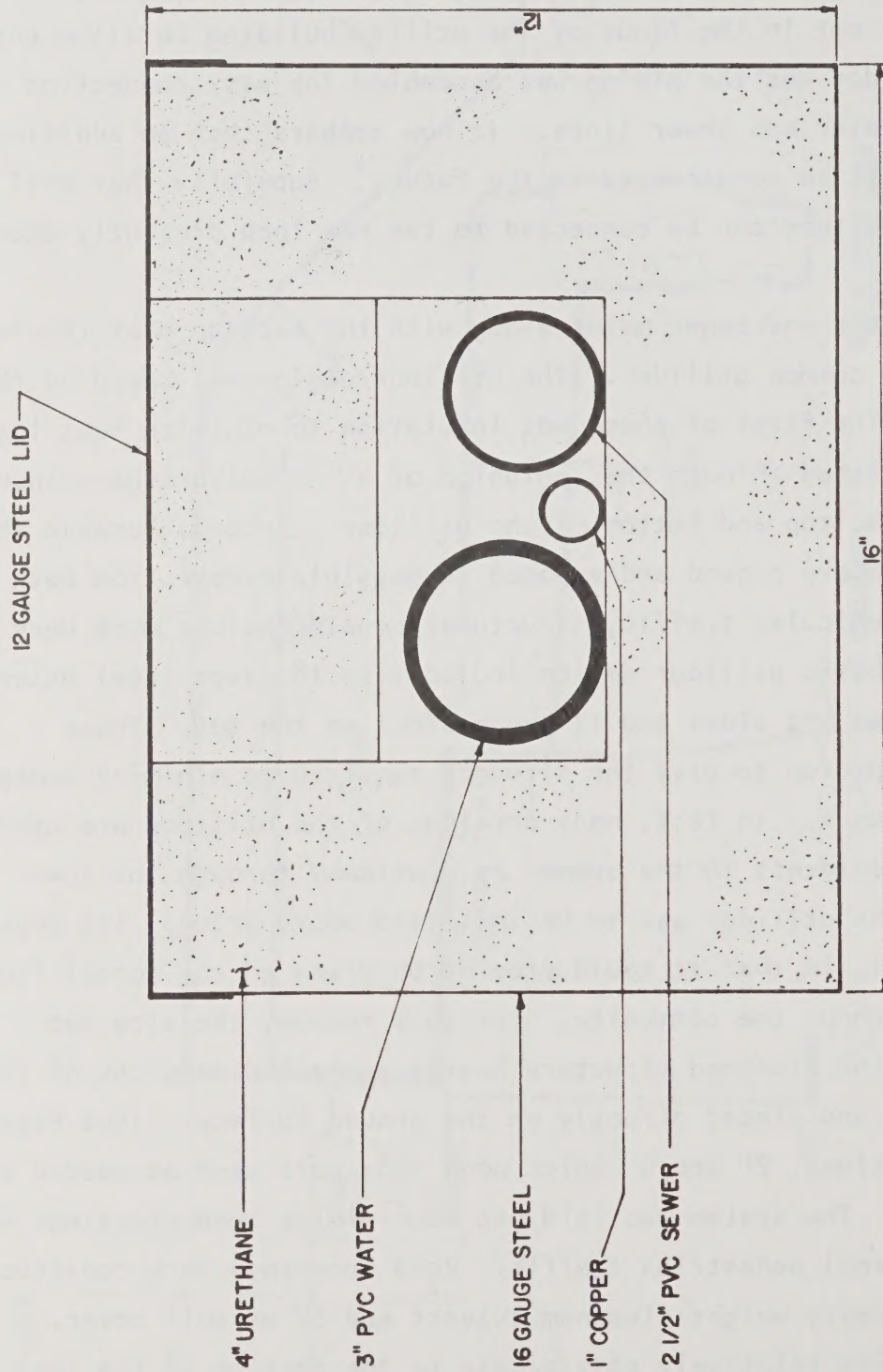


FIGURE 3. UTILIDOR DETAIL

section of the aluminum culvert. Since much winter traffic in Noorvik is by snowmobile, wooden ramp crossings were constructed at locations where routine snowmobile traffic does not follow the existing road system.

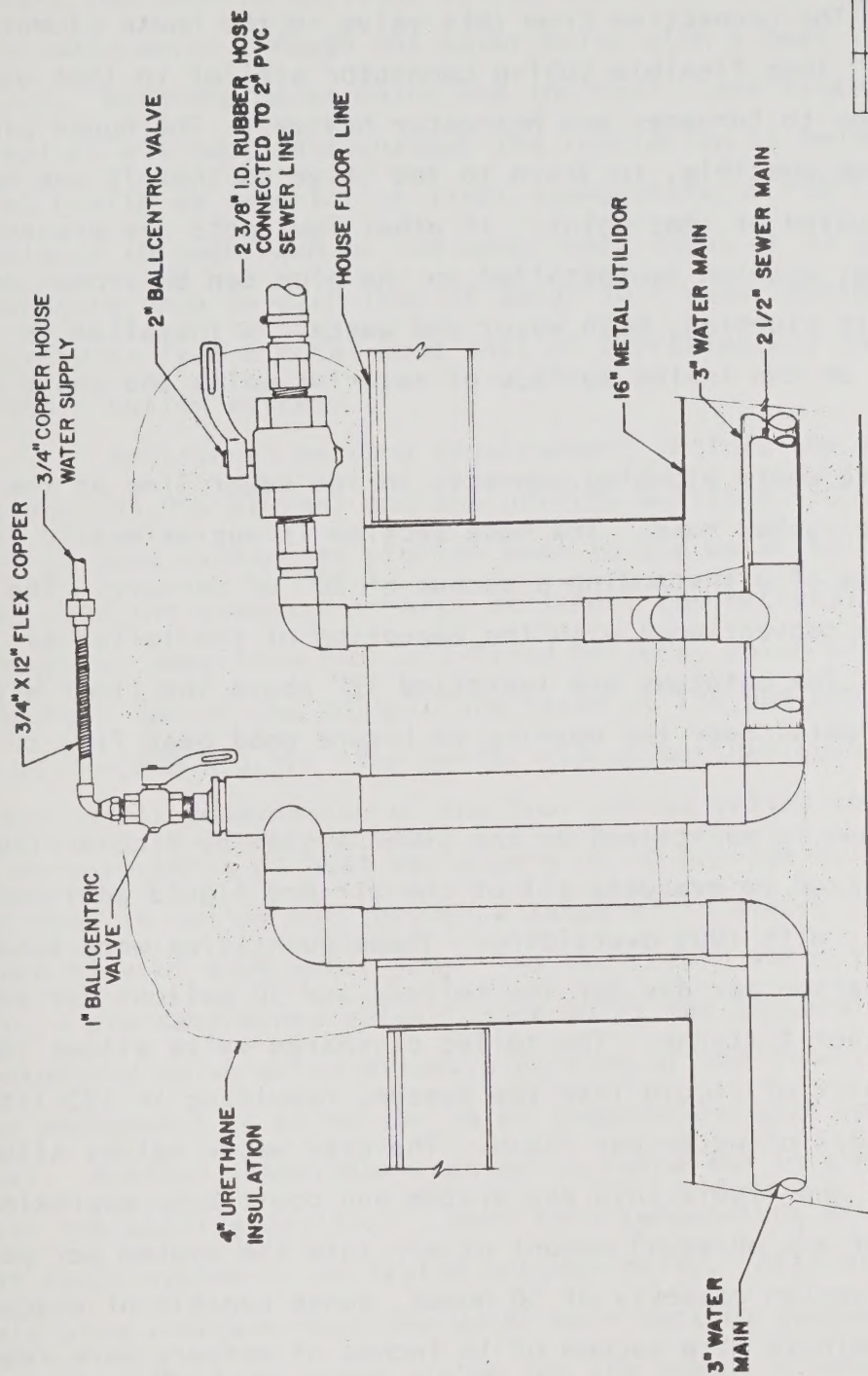
Pipe size for the sewer mains was based largely on discussions held with AB Electrolux concerning their experience with existing systems. The smallest practicable line was also desired to increase the rate of movement in the sewer mains and to minimize the operating costs of the vacuum pumps. These criteria resulted in PVC sewer mains of 2 1/2" diameter. The sewer system layout also incorporates several shut off valves which are full opening ball valves. These valves will be utilized much the same as isolation valves in a conventional water system are used when searching for or repairing leaks in the main. No problems have arisen to date due to the collection of debris on the valves and they have functioned exactly as required when necessary.

The water mains are 3" PVC pipe and utilize the same type of isolation valves as the sewer mains. Also included at approximately 500 foot intervals throughout the system, are short valved tees with fire hose adapters. (See Figure 4.) These valves are located on top of the utilidor with a removable insulated box located over each and were included in lieu of fire hydrants since the system is above ground.

The heat tracing system was designed strictly for backup since the circulating water mains are the primary heat source for the utilidor system. The trace lines are 1" copper with soldered joints and have expansion joints located about every 150 feet. The trace lines are filled with a 50% mixture of ethylene glycol and water and are activated automatically in the event of shut down of the water system.

SYSTEM DESIGN DETAILS

The houses are connected to the utilidor through a utilidor-like insulated riser. (See Figure 5.) The dimensions of this riser are such that it fits between two floor joists. A piece of flexible weather-stripping material is attached to the bottom of the house sub-floor and goes completely around the riser to prevent cold air from entering the house. The riser is not attached to the house to allow independent movement of



TYPICAL HOUSE CONNECTION

DATE	REVISIONS	INITIALS
U.S. Department of Health, Education & Welfare Public Health Service Indian Health Service		
NOORVIK, ALASKA		
PROJECT NO.	PUBLIC LAW 86-121 PROJECT	SHEET NO.
DATE	DATE	TOTAL SHEETS
SANITATION FACILITIES CONSTRUCTION BRANCH OFFICE OF ENVIRONMENTAL HEALTH ALASKA HEALTH DEPARTMENT ANCHORAGE, ALASKA		

FIGURE 5. TYPICAL HOUSE CONNECTION

the house and/or the utilidor with the freeze-thaw cycle. Inside each house, a 3/4" stop and waste valve is installed on a tee, off of the water main loop. The connection from this valve to the house plumbing is made with a 12" long flexible tubing connector similar to that used for gas connections to furnaces and hot-water heaters. The house plumbing is graded, wherever possible, to drain to the valve so that it can be isolated and evacuated at that point. If other low spots are present in the house plumbing, a union is installed so the pipe can be broken and drained. All house plumbing, both water and waste, is installed in interior walls or on the inside surface of exterior walls and above the floor surface.

The house waste plumbing connects to the sewer line at the riser through a flexible rubber hose. The hose section is approximately 24" long and is capable of withstanding a vacuum of 20" of mercury. The house fixtures are conventional with the exception of the toilet as mentioned before. The bathtubs are installed 12" above the floor with a sheet of expanded metal over the opening to insure good heat flow to the plumbing.

The vacuum is maintained on the sewer system by liquid ring vacuum pumps which were sized to evacuate all of the air and liquid admitted to the system by 50 homes, with 100% oversizing. These quantities were based on 6 flushes per person per day for the toilets and 30 gallons per person per day for the other fixtures. The toilet discharge valve allows 100 parts of air per part of liquid into the system, resulting in 120 liters of air and 1.2 liters of water per flush. The gray water valves allow equal parts of air and liquid into the system and contribute approximately 30 gallons of water and an equal amount of air into the system per person per day. For the design capacity of 50 homes, pumps capable of evacuating 60 cubic feet per minute at a vacuum of 16 inches of mercury were required. The pumps installed are SIHI Model 3408 liquid ring vacuum pumps.

The vacuum collection tank was sized similar to the sizing of a lift station wet well, resulting in a capacity of 6000 gallons with the 60 gallon per minute sewage pumps cycling every six hours at the design flow. Only one-half of the vacuum tank capacity is used for liquid storage with the other half full of air serving as a buffer for the vacuum pumps.

The most complex portion of any arctic water system, as well as the most unique, is the heating equipment and controls. As stated earlier, the Noorvik utilidor system was designed to be heated by circulating warm water through the water mains with a heat tracing system for back-up. Both the water mains and the heat trace systems were designed to replace all heat lost through the insulation at an outside air temperature of -40°F with an interior utilidor temperature of $+40^{\circ}\text{F}$. Water is circulated through each of two water main loops at 30 gal/min with a temperature drop in each loop of about 20°F under design conditions. This results from a total heat loss of approximately 54,000 BTU/hr in the distribution system.

Additional heating requirements include the sewage discharge utilidor (35,000 BTU/hr) and the utility building (103,400 BTU/hr). Three pairs of heat exchangers provide heat to the water mains, heat trace lines, and the sewage discharge utilidor, respectively. Heat for the exchangers comes from four oil-fired boilers, which also heat the utility building. Two of the boilers are rated at 174,000 BTU/hr and the other two at 314,000 BTU/hr. The boiler piping was designed so that any one boiler and/or combination of the four can be valved to add heat to any one or more pairs of heat exchangers or to provide building heat. Water main heat is called for through a temperature sensor installed in the return side of each water loop. As the return water temperature drops below a pre-determined value (about 40°F) the temperature sensor activates a motorized valve which allows a portion of the flow to go through the heat exchangers to bring the water temperature back up to its desired level. Another temperature sensor is installed in the utilidor underneath the utility building. When this temperature drops too low, the heat trace system is activated automatically. Activation of this sensor would also indicate that the water main heating system is not working properly. The heat trace system for the sewage discharge line is operated manually to maintain a pre-determined temperature in the utilidor, since it provides the only heat source for this line.

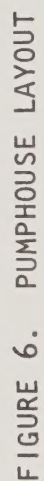
The sewage discharge line is enclosed a small wooden utilidor insulated with 4" of polystyrene insulation and was constructed on the job site. Included in the utilidor with the 4" PVC pressure sewer main is a 1"

copper heat trace loop. The sewage line discharges into a natural pond which has been converted into a sewage lagoon, 1,300 feet from the utility building. The discharge point is approximately 100 feet into the pond. In this area, the utilidor is supported by small diameter steel piling which were driven to refusal. The pond is completely fenced and drains away from the village, finally discharging into the Kobuk River about one mile downstream.

One of the major problems with providing any type of sanitation facilities in Noorvik was the lack of a dependable, year-round water source. Several unsuccessful attempts at well drilling had been made in the past with holes drilled to nearly 300 feet. A geophysical exploration crew in the area was contacted and found water at 700 feet but the water was salty. All lakes in the area are small and shallow and not suitable for a year-round source. The Kobuk River, which flows past the village, has adequate quantities of good quality water but the ice and flooding problems preclude the construction of a permanent intake. A shallow well drilled on the river bank into the underlying thaw bulb also yielded no water.

As a result of these investigations, an intermittent pumping water supply system using the Kobuk River as a source was chosen and constructed. The 100,000 gallon steel water storage tank was sized to store two weeks supply for the design population. Pumping from a floating intake with a submerged inlet in the summer and from a hole in the ice in the winter has been working very well. Two weeks storage is sufficient to preclude the necessity of pumping during spring break-up of the river. The water is chlorinated and fluoridated as it enters the utility building. A sand filter system is presently being designed. From the storage tank, a conventional hydro-pneumatic system provides pressure to the mains. A schematic flow diagram of the utility building piping is shown in Figure 6.

Several alarm devices have been incorporated into Noorvik's water and sewer systems. These include low water temperature, low flow, and low storage tank level alarms for the water system; a high liquid level alarm for the vacuum tank on the sewer system; and a loss of power alarm for both systems. Any of the alarms activates a siren on the exterior



of the utility building. The control system prevents damage to the circulating pumps by not allowing them to operate after the flow switches sense a no-flow condition. Similarly, when the high level alarm in the vacuum tank is activated and the liquid level continues to rise, further operation of the vacuum pumps is prevented. A manual start standby generator is also located in the utility building. All critical circuits can be switched to this unit through a single switch.

An additional cost which was not directly related to construction resulted from a freeze-up and the accompanying repair and thawing of a portion of the water system. This problem occurred soon after start-up of the system in the late fall of 1974 and was due to a fabrication error in the control panel and a lack of knowledge on the part of the operator. The circulating pumps were inadvertently shut down and the addition of heat to the system ceased. The heat trace system came on automatically on one of the utilidor loops and prevented any damage but the other water loop froze and broke since that portion of the heat trace system was not yet operational.

Operational costs for the system are estimated to be approximately \$30,000 per year. (See Figure 7.) When spread over all users based on projected usage, about 22% of this total can be attributed to the 18 individual homes; 3% to the clinic; and 75% to the high school, teachers quarters, and classroom units. All pumps are presently being fitted with hour meters so the actual running time of each can be accurately calculated over any given period. A totalized fuel meter is being installed in the main oil feed line to the boilers so actual oil usage can be determined. Additional meters will be installed on individual boilers so total heat requirements can be broken down for different heat demands. One year's record from these meters along with the existing water and electrical meters will give a very accurate picture of operating expenses.

COSTS

The original Noorvik system was constructed for a total capital cost of \$777,000. These funds provided piped water and sewer service to 18 individual houses, 4 school classroom units, 2 teachers quarters, a

1. POWER - 49,000 KW-HR/YEAR @ 20¢/KW-HR	\$ 9,800
2. FUEL - 7,344 GAL @ 50¢/GAL	3,672
3. SALARY - 1 MAN-YEAR	10,000
4. EQUIP. REPAIR & REPLACEMENT	2,500
5. CHEMICALS	<u>500</u>
SUBTOTAL	\$26,472
10% CONTINGENCY	<u>2,647</u>
TOTAL ANNUAL COST	\$29,119

BREAKDOWN BASED ON % OF USAGE:

1. VILLAGE - 22%	\$ 6,406.18
2. SOS - 10%	
(ELEMENTARY SCHOOL & TEACHER'S QUARTERS)	2,911.90
3. SOS (HIGH SCHOOL) - 65%	18,927.35
4. CLINIC - 3%	<u>873.57</u>
	\$29,119.00

COST PER HOUSE PER MONTH

$$\frac{6,406.18}{12 \text{ (18)}} = \$29.66 \text{ SAY } \$30.00$$

FIGURE 7. NOORVIK - ESTIMATED OPERATING COSTS

health clinic, and a new high school. Major portions of this construction cost included \$75,000 for the pile foundation and floor for the 50 ft by 100 ft utility building; \$225,000 for the building shell itself with the water storage, hydropneumatic, and vacuum tanks; \$161,000 for 6,625 ft of utilidor installed; \$25,000 for the special equipment for the vacuum system; and approximately \$30,000 labor costs for house plumbing.

The houses were already plumbed for conventional sewers and the fixtures installed. The conversion work required more time than would an installation in an unplumbed house.

Because the project was constructed over a three year period, costs changed from year to year. The utilidor, installed with pipes included, cost \$22.33 per foot in 1972 and was up to \$37.73 per foot by 1974. However, these costs compare very favorably with the combined cost of buried gravity sewer and water systems of approximately \$50 per foot installed, and are much lower than the \$200 to \$500 per foot figures often quoted for utilidor installations.

PRESSURE SEWAGE COLLECTION SYSTEMS IN THE ARCTIC

by

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U.S. Indian Health Service
Anchorage, Alaska

INTRODUCTION

The Indian Health Service (IHS), Alaska Area Office of Environmental Health, Sanitation Facilities Construction Branch has the responsibility of improving the health of Alaska Natives through the provision of safe and sanitary water supply and waste disposal facilities. IHS receives funds for the design and construction of the facilities but their operation and maintenance after construction is the responsibility of the community and must be funded through user fees. A facility that the community cannot afford to operate and maintain will fail so this is the primary consideration in the design of systems to serve the Native communities.

The goal of keeping the operating and maintenance costs low is a difficult one to obtain when facilities must be constructed in permafrost areas of the arctic. Water must be circulated so what is not used returns to a central pump house where it is reheated and recirculated. Sewage collection systems vary from single gravity systems in thaw-stable ground, such as well drained sand or gravel, to pressure or vacuum systems in areas subject to frost heaving where the facilities must usually be placed above ground. With pressure or vacuum systems, one must consider the addition costs of pumping and the increased heat loss experienced when the lines are located in the -20 to -40° outside environment.

PRESSURE AND VACUUM COLLECTION SYSTEMS

Much of the permafrost area of Alaska consists of ice rich silts and clays which are classified as highly frost susceptible and are unstable with considerable settlement upon thawing. Nearly all the communities in the Lower Yukon, Kuskokwim River, and Kotzebue-Nome areas have these soil conditions. These communities account for about 2/3 of the some 220 native communities in Alaska. Gravity sewage collection systems are usually not suited to these conditions whether they are placed above or

below ground. If below ground, the movement of the lines caused by frost heaving or settlement can easily alter the grades to the point the lines will no longer function or even be pulled apart. Placing a gravity sewage collection system above ground is a very expensive and unsightly solution. Holding grades above ground requires lines on piling at varying heights above the surface which in turn means the building plumbing systems must be placed even higher than the collection lines outside or a pump must be supplied to lift the sewage into the collection lines. The lines on piling interrupt foot and vehicular traffic throughout the community and are prone to vandalism. Either roads, foot paths, etc. must be elevated over crossings with the lines or the lines must dip under or be elevated over the roads, etc. which will usually require pumping. Because of these items, IHS started looking to other non-gravity sewage collection systems which would do away with these disadvantages and yet be as simple and foolproof as possible and not be too expensive to operate and maintain. The two most likely solutions are vacuum and pressure systems. This article will concentrate on pressure type systems. The vacuum collection system have been covered in detail in another article by Dan Rogness and myself.

Advantages of Pressure Type Collection Systems

A pressure sewage collection system is usually a combination of pressure lines and conventional gravity lines. In fact, any gravity collection system usually has an occasional lift station with pressure or force mains. There have been several tests and prototype installations around the United States which have tested the pressure system concepts and hardware. The two primary problems encountered have been the reliability and durability of the small pump-grinder units, which usually pump the sewage from each building, and the hydraulic design of the collection lines to prevent grease deposition. Both of these problems seem to have been solved. The advantages of pressure type system are:

1. The collection lines are much smaller. They usually vary between 1 1/4" and 3" depending on the number of units contributing while gravity lines start at 4" and increase in size from there.

2. The collection lines do not have to be graded and can lay on and follow the surface of the ground (or shallow bury) without the need for elevation. For instance, the sewer lines could be laid with the circulating water lines in a small, relatively inexpensive, utilidor which follows the natural contours of the ground.
3. Actual installations have experienced considerably lower (by two-thirds) and more concentrated sewage flows than with gravity systems because of no infiltration. This concentration of the sewage makes for more efficient sewage treatment, also.
4. If each home or building is supplied with a pump grinder unit the individual tenant or owner is the person that suffers if he doesn't take care of his installation. His negligence does not jeopardize the entire system. Also, he will be more prone to reducing water use as his sewage costs will be more directly related to his water use. This system encourages the use of low water use fixtures, etc. The individual would pay a large part of the sewage system operating costs along with his electrical bill each month. All maintenance costs on the unit within an individual building or house can be paid for as the work is done by a maintenance man hired and trained by the municipality.
5. The pressure systems also have some advantages over the vacuum systems. Vacuum systems are limited to a difference in elevation of 15' to 20' from one part of the system to another. Pressure systems are not limited in allowable elevation differences. Also, the vacuum collection lines require traps approximately every 150 feet to reestablish plug flow. Pressure lines can be designed for nearly any number of houses while a given vacuum line can probably not serve more than 30-50 houses. Vacuum systems require special plumbing, toilets, and rather complicated vacuum discharge valves on

sinks, lavatories, etc. but pressure systems can use conventional or low water-use plumbing fixtures. Also, a vacuum system can increase infiltration if the lines are buried while a pressure system completely eliminates it.

Disadvantages of pressure collection systems

The disadvantages of a pressure collection system are:

1. There are small pump grinder units located in each building spread out around the community instead of having all pumps, etc. located in a central pumphouse. This makes it more difficult to provide standby power for operation of the entire system in the case of an extended power outage. Power outages are rather common but those of short duration (probably twelve hours if water use is curtailed) could be handled by providing a larger holding tank (sump) for the pump grinder unit to pump from at each house.
2. Probably the largest disadvantage of the pressure system is the maintenance and reliability of the individual pump-grinder units. Many improvements have been made in them in recent years that have resulted in large increases in reliability. These will be covered in detail later. Also, to provide 100% standby, two complete pump-grinder units should be supplied in each building sump. They can be wired or controlled so, if the initial one fails to operate, a warning alarm is activated and the standby unit takes over.
3. There is a greater possibility of contamination of a water line placed in a utilidor with a pressure sewage collection line than there is with either a gravity or vacuum line.

BETHEL, ALASKA PRESSURE SYSTEM

Introduction

The Indian Health Service designed and installed a modified pressure sewage collection system in the City of Bethel, Alaska in 1970. The U.S.

Department of Housing and Urban Development (HUD) funded the construction of 200 units of low income, single family housing in a subdivision (Bethel Heights) about 1 1/2 miles back from the river. The existing town is located immediately on the Kuskokwim River and floods almost yearly. The flooding and erosion of the permafrost banks along the river made it impracticable to serve the existing town with piped water and sewer and they utilize trucks to haul water at 4¢ per gal and pickup honey bucket wastes at an additional 4¢ per gal. Under the haul system, water use rates are about 5 gpcd. From experience in other communities in Alaska, a design use rate of 70 gpcd was selected for the housing area served with piped facilities. It was also assumed that all water would return as sewage with the piped facilities.

The total population of Bethel is about 2,500 with around 1,000 people living in the 200 unit subdivision called Bethel Heights. The layout of the subdivision was accomplished by the Alaska State Housing Authority and good community planning practices were not followed. The main problem was the lack of drainage facilities. The roads were laid across the slope instead of with the slope. The roads consisted of about 2 feet of sand end-dumped on the surface of the tundra. Culverts were not provided and each road became a small dam preventing the drainage of surface water. Figure 1 shows the layout of Bethel Heights. Construction of the houses started in 1969 and was completed in 1970. They were constructed in a central plant and then moved to the housing site where they were placed on posts and pads (four per house). The wood pads were laid directly on sand pads formed as the roads had been. The original depth to permafrost in the undisturbed tundra was about 18 inches and the permafrost consisted of ice rich silts beneath the 6 inches of mosses. Figure 2 presents a typical soil boring for the area and Figure 3 shows a soil temperature vs depth curve for the years 1968 and 1969. Even though there is 400 ft of permafrost at Bethel, it is marginal, i.e. its temperature is very near thawing (30 to 32°F). Thus the least disturbance to the insulating moss layer will cause considerable thaw and settlement because of the high ice content.



FIGURE 1

U. S. Department of Health, Education & Welfare
Public Health Service

DIVISION OF INDIAN HEALTH

BETHEL HEIGHTS, AK.

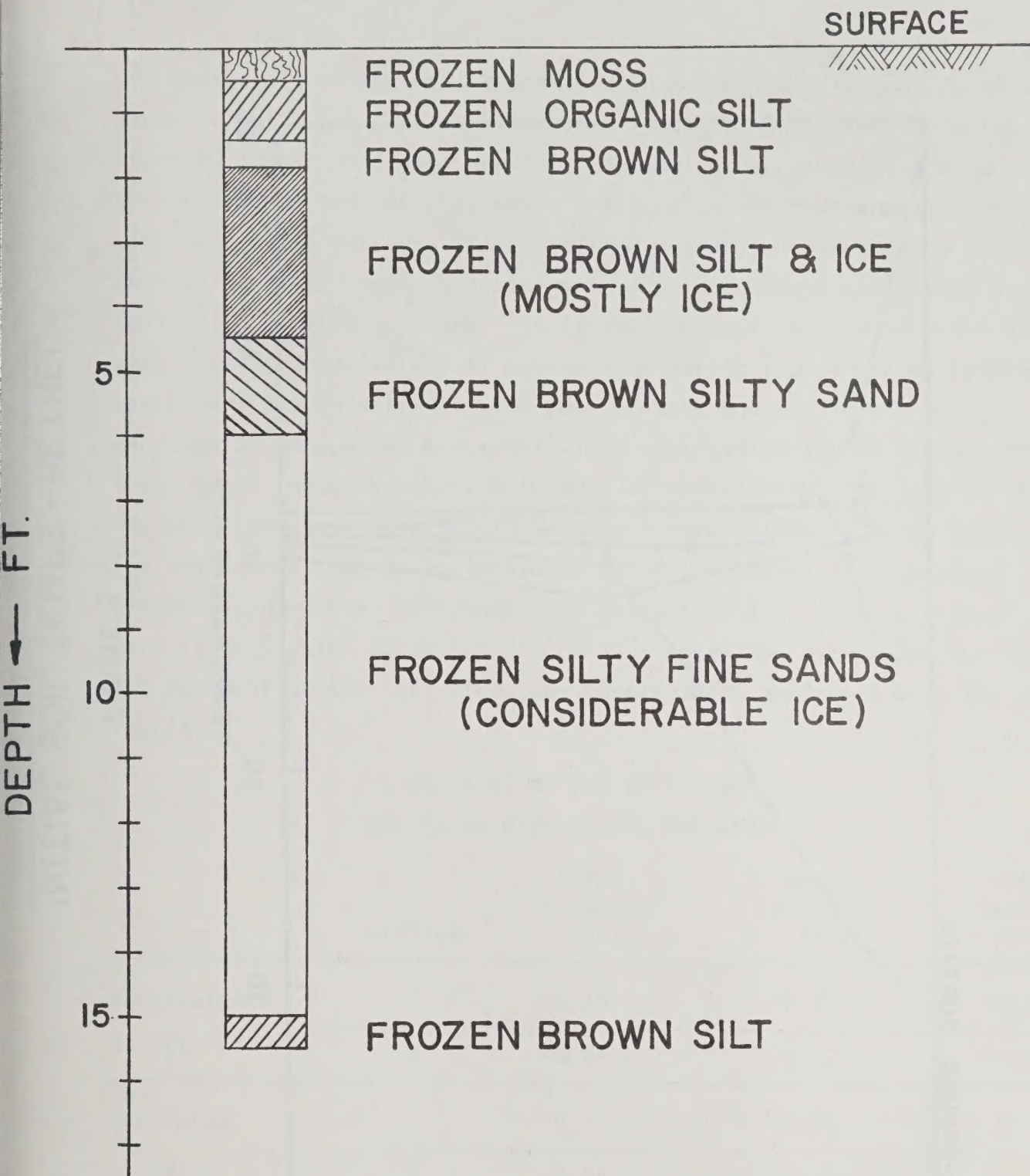
POSITIVE PRESSURE SEWAGE SYSTEM

PROJECT NO. AM 78-153

TOTAL SHEETS 78

DATE	NAME
CHECKED BY	DVP as needed

SOLIDATION FACILITIES CONSTRUCTION BRANCH
OFFICE OF ENVIRONMENTAL HEALTH



TYPICAL SOIL BORING - BETHEL
FIGURE 2

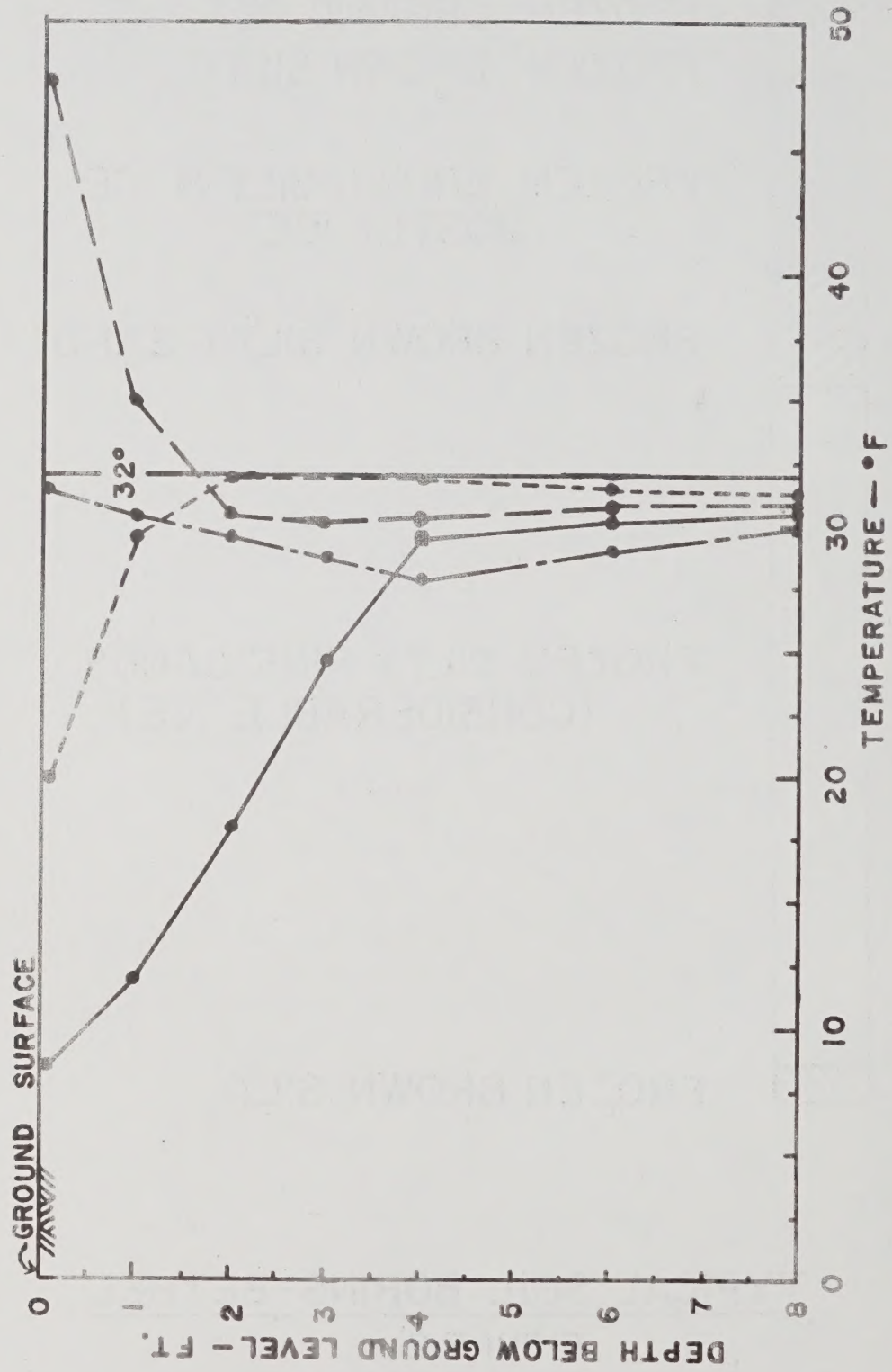


FIGURE 3

INITIAL SOIL TEMPS. - BETHEL

Preliminary Tests

IHS was obligated to provide water and sewer facilities for these 200 houses plus a Regional Boarding High School with student dorms and a grade school. Later a laundromat and 75 units of apartments in two story buildings were also served. The sanitation facilities were to be constructed as soon as physically possible so the houses would have water and sewer service. As an interim measure, water holding tanks and chemical toilets (honey buckets) were provided with distribution and collection service by truck. It is usually desirable to go below ground with the piped facilities if possible so during the winter of 1968-69 tests were run to determine the rate of thaw and settlement to be expected if warm water and sewer lines were buried in the silty soils. These tests indicated that, with adequate insulation, the rate of thaw and resultant settlement could be kept within allowable proportions. The tests consisted of an insulated (2" of urethane) 3" galvanized pipeline and another uninsulated 3" galvanized line laid at a depth of 4 feet through which about 3.5 gpm of 45°F water was circulated for nine months. The movement of the test lines was continuously monitored with the following results:

MOVEMENT OF THE TEST LINES DUE TO THAWING OF THE PERMAFROST*

	STATION	AFTER 5 MONTHS (ft)	AFTER 7 MONTHS (ft)	TOTAL 9 MONTHS (ft)
Un-insulated	1	-0.10	-0.23	-0.53
(A)	2	-0.64	-0.97	-1.79
Insulated	1	0	-0.01	0
(B)	2	-0.04	-0.05	-0.05

* (-) Signifies below original position

Station 1 is at the beginning of each Test Loop

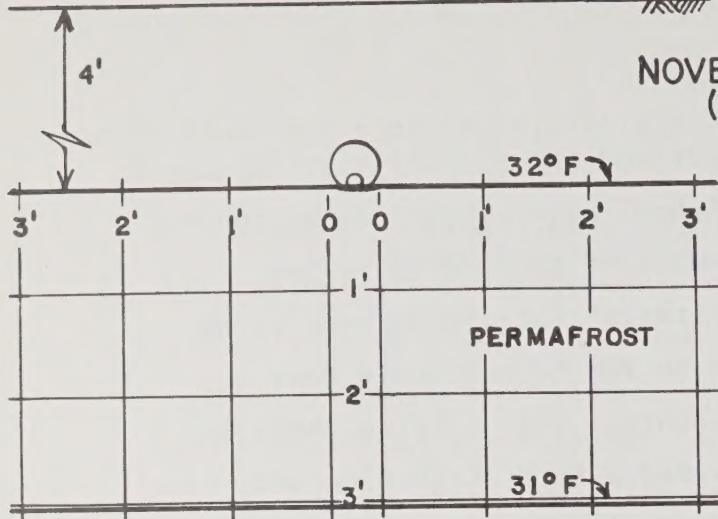
Station 2 is at the end of each Test Loop

Test Loops were each 60 feet long

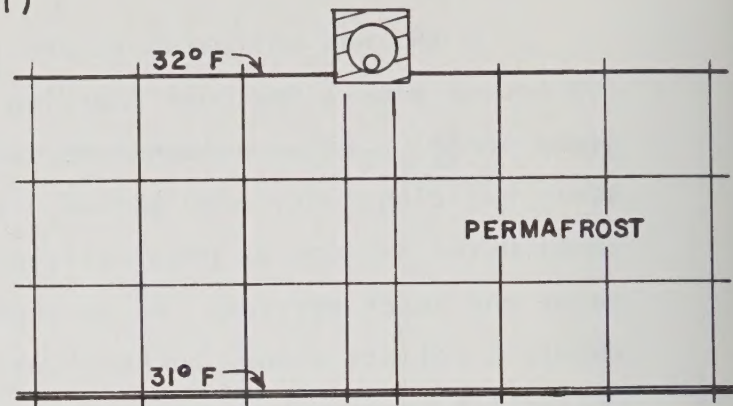
The resultant thaw beneath the lines is shown in Figure 4.

UN-INSULATED LOOP (A)

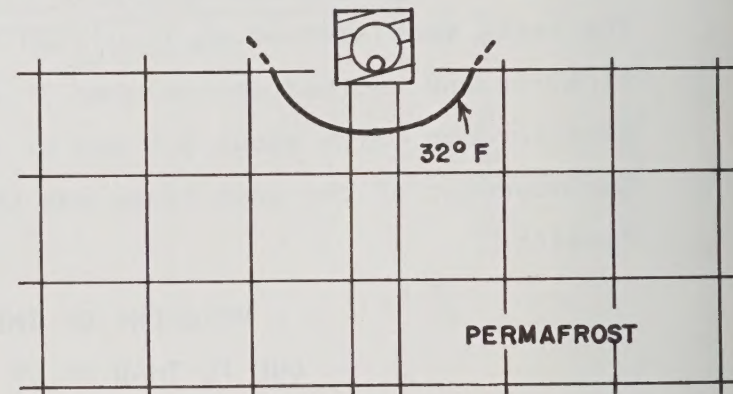
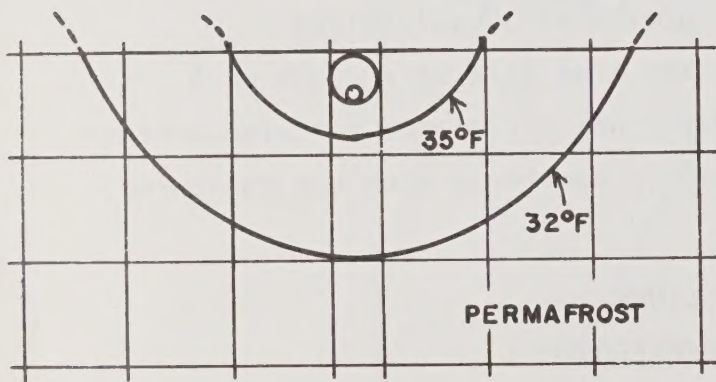
GROUND SURFACE



INSULATED LOOP (B)



(B)

APRIL 1969
(AFTER 5 MO.)

(C)

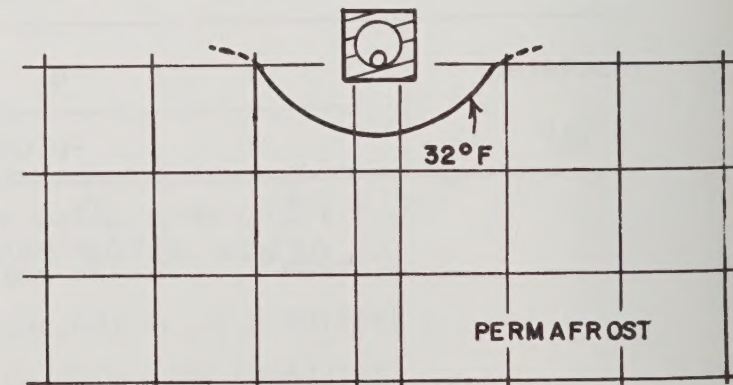
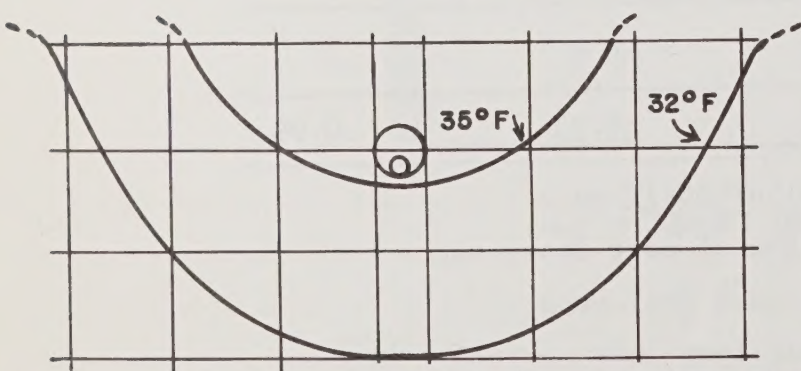
AUGUST 1969
(AFTER 9 MO.)

FIGURE 4. PIPELINE SETTLEMENT TESTS - BETHEL

Design

The decision was made to bury the insulated water and sewer lines near the top of the permafrost after its upper surface had adjusted to the road and house pad construction. Heat losses could be reduced, vandalism eliminated, damage by cars and snow-machines eliminated, and unsightly obstructions throughout the subdivision reduced by burying the lines. In burying them at, or near the final permafrost upper level (estimated to be 4') it was felt movement due to frost heave could be considerably reduced. Some movement, however, was expected due to permafrost thawing, probably too much to be able to rely on a complete gravity collection system. Thus a modified pressure sewage collection system was designed and constructed. The water system was a heated, circulating, looped system. The houses were laid out in cul-de-sacs of six which made them considerably more difficult to serve with piped facilities. It was decided to collect the sewage from three to six houses (depending on the layout) by gravity to a central point among the houses where a small pump station would pump the sewage to a holding tank at a central pumphouse for transfer to the sewage lagoon. Because of the distribution of the houses, this meant 48 pump stations to serve the 200 houses, vacant lots among the houses which would be built on in the future, and the apartment buildings. Because of the expected movement due to freezing and thawing, a minimum slope 2% was used for the short gravity collection lines to the pump stations. An additional safety factor would have resulted if the lines could have been bedded in gravel, but this was impossible in this area. The nearest source of gravel to the Kuskokwim delta is over 100 miles up-river from Bethel. Even there, a coarse sand is about all that is attainable. The material must be barged to Bethel at about \$25.00 per cubic yard. In fact gravel can be barged from Seattle to Bethel for about the same cost. Canadian engineers complain of the shallow bedrock they have to work with, but it would be a welcome change to the ice-rich silts in the Yukon-Kuskokwim delta areas.

The pump stations were the pneumatic type that would discharge 40 gpm at 60 feet of head. Their method of operation is shown in Figure 5. They were tied into four operating "banks", electrically, with each bank metered separately. Each pump station had two identical compressors

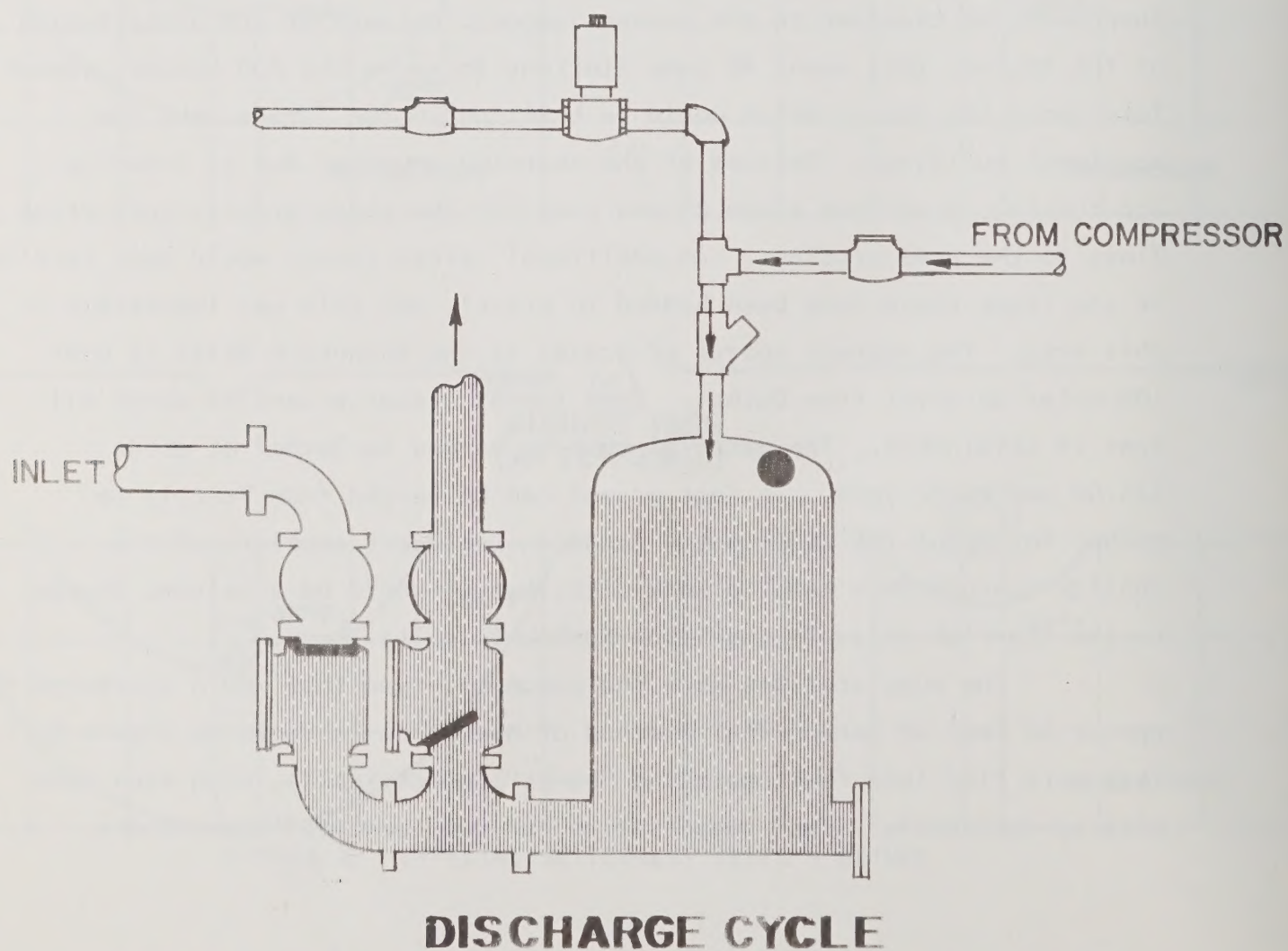
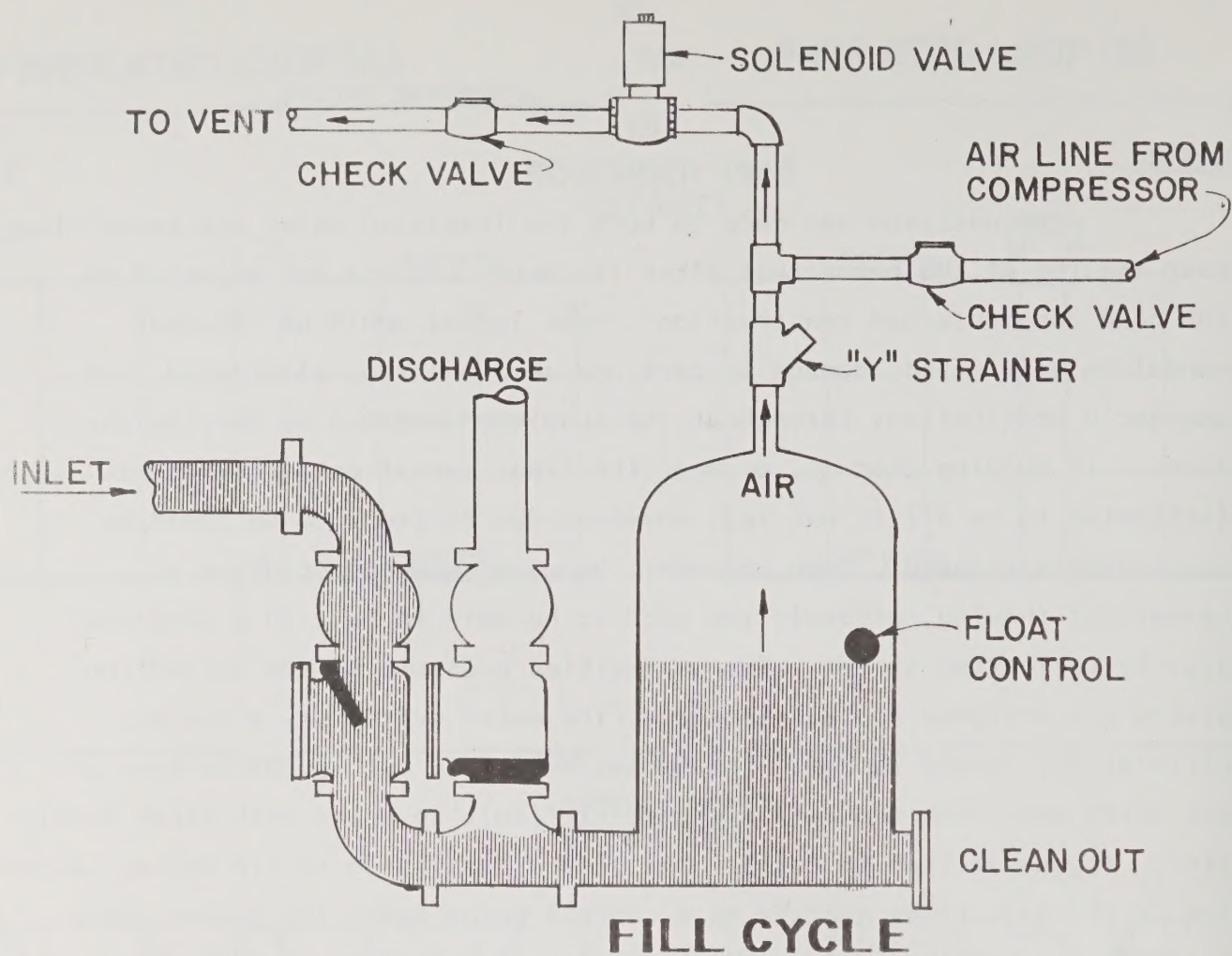


FIGURE 5

with 220 volt, 3 phase, 1 horsepower motors for 100% standby operation. If the prime unit would not start for some reason, the floats would trigger an alarm light located about 4 feet in the air on the outside of the station and an audible alarm to alert the maintenance man that the primary compressor was not working. In the meantime the standby unit would take over in place of the primary unit. The main part of each station is 7 feet high and 6 feet in diameter tank with a 50 gallon sump capacity. Manholes, 3 feet in diameter, of varying lengths lead down into the stations and the entire station was insulated with at least 3" of sprayed on urethane foam insulation. A two cubic yard concrete slab was bolted to the bottom of each station for weight and three inches of urethane board stock was laid under the slab when the lift stations were installed (totalling about 6 inches of insulation underneath). The stations cost \$4100 each, FOB Seattle in 1969. The second lowest bidder was a submersible pump type station at \$5950 each.

The facultative sewage lagoon used to treat the sewage was formed by diking up the low points around an existing shallow lake (about 3' deep). The design depth is 7 feet and the surface area is 16 acres or about 150 people per acre including the hauled waste from "downtown". The lagoon is located about one-half mile from the 4000 gal hoppers holding tank in the main pumphouse and 1500 feet from the nearest dwelling.

The pressure sewage collection lines are 4 inch insulated pipe (See Figure 6) and are laid in loops which originate and terminate in the pumphouse. At present prices, this pipe costs about \$5 per foot FOB, Seattle. The capability of adding warm water at the end of the sewage collection loops was designed into the system. The temperature of the incoming sewage (from the pump stations) was monitored and, if it dropped below 45°F at night (low flow), a pump drawing from a warm water storage tank could pump 65°F water into the end of the loop to be circulated around the loop and back to the holding tank. This circulating pump could also be used to flush the lines occasionally and clean out solids which may have been deposited. The looped sewage collection lines were also fitted with polyurethane "Poly-Pig" launchers at the ends in the pumphouse to allow cleaning or de-watering of the collection lines and the line to the lagoon if the need arose. Ten horsepower non-clog sewage pumps

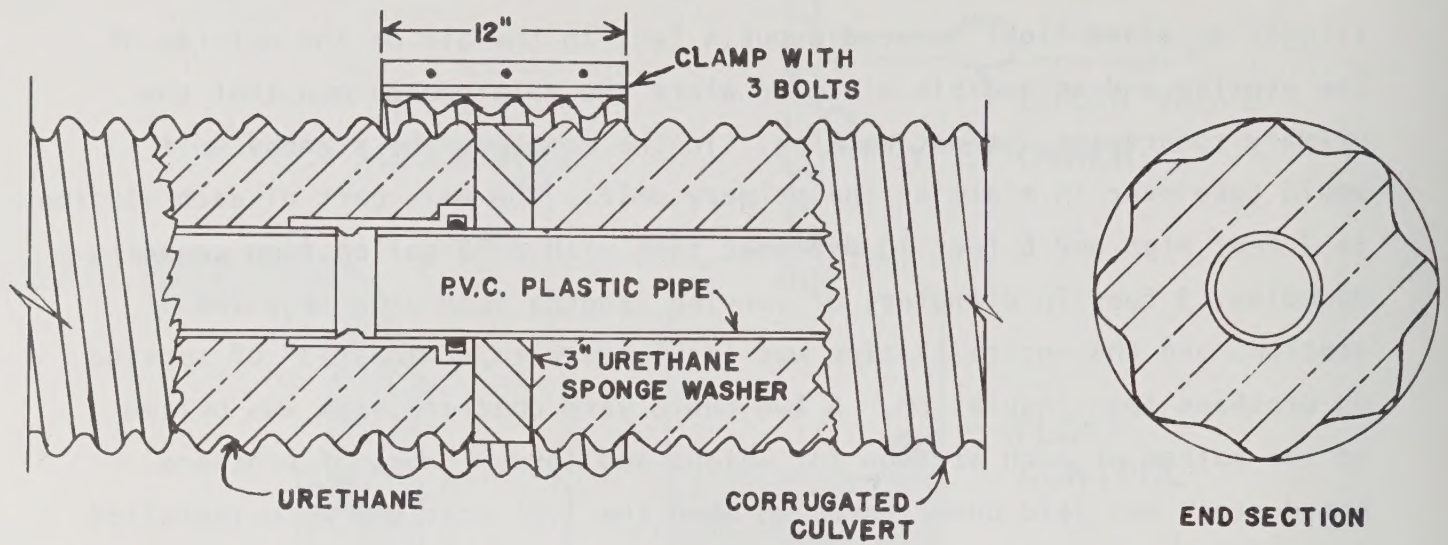


FIGURE 6

INDIAN HEALTH SERVICE
INSULATED PIPE-BETHEL

take the sewage from the 4000 gallon holding tank and pump it to the sewage lagoon. The pumps have float type mercury switches in the tank which turn them on, off, and actuate an alarm if the primary one fails to operate or keep up with the load.

Construction

The initial contract construction costs (1969) for the sewage system for Bethel Heights broke down as follows:

1.	Sewage lagoon	\$ 25,900
2.	Pump Stations (48 @ \$4100 ea. FOB Seattle)	196,800
3.	Pump Station shipping, installation and insulation (48 @ \$2050 ea.)	98,600
4.	Electrical lines, transformers, etc. to and from the four "banks" of pump stations.	34,900
5.	Waste holding tank (in place) in pumphouse	6,800
6.	Pumphouse and plumbing attributable to sewage system including lagoon line pumps.	33,000
7.	Sending traps and "pigs"	3,200
8.	House connections between gravity lines and houses (allow about 8" of movement) (48 @ \$485 ea.)	97,000
9.	4" PVC by 12" culvert-insulated pipe (FOB Seattle) 24000 feet @ \$4.80/ft	115,200
10.	Excavation of frozen ground for pipes 5000 cubic yd @ \$20/yd ³	100,000
11.	Excavation of thawed ground for pipes 1500 cubic yd @ \$5.25/yd ³	62,500
12.	Shipping and installation of all insulated pipes (all excavation included above, #10-#11)	
a.	12,169 ft of gravity collection lines (house to pump station) @ 9.60/ft	116,200
b.	2440 ft of pressure lines (pump station to collection lines in street ROW) @ 9.50/ft	23,200
c.	800 ft of pressure collection lines (from pumphouse) @ \$7.30/ft	19,000

d. 2600 ft of pressure line to lagoon from	
pumphouse @ \$7.30/ft	19,000

Total initial construction costs (1969) attributed
to the sewerage collection and treatment system = \$1,000,300

There was only one bidder and the contract for construction of the water and sewer system was awarded to him. He was well entrenched in Bethel, having a roadway job, airport extension and apron job, and the contract for construction of the 200 HUD houses. He was, however, in financial trouble and lacked experience in utility construction, especially in frozen ground. The contract was awarded in June 1969 with the contractor planning to complete the pipe laying and outside work by November of 1969 and all inside plumbing, etc. by March 1970. He immediately fell behind schedule because he could not dig in the water saturated areas around the houses and uphill sides of the roads. As explained before, this saturation was from runoff and snowmelt being dammed by the sand dumped on the tundra for house pads and roads with no provision for drainage. He then decided to wait until the ground froze, obtain a larger backhoe, and dig the ground in the frozen condition. The frozen silts were extremely hard to dig and he was well into the next summer with only about half of the pipe in. Also, runoff water entered some of his completed lines because he had not capped and protected them properly. It was still freezing at the depth of the pipes, so this water froze and split several hundred feet of pipe which had to be replaced. When the systems were about 2/3 completed in late 1970, the contractor declared bankruptcy; IHS terminated the contract, and proceeded to complete the installation using their own crews. The facilities were completed in November 1971 and placed in operation in January 1972. There were additional costs due to the contract termination and settlement. IHS had to purchase equipment, and there were labor costs for the force account completion of the project. These additional costs were \$508,700 for the system and for treatment about \$1,509,000. Discounting the cost to enlarge facilities to serve the school (funded by State of Alaska) and apartment complex (funded under a later project), the cost per house amounted to about \$7,550. It must be remembered, these are costs four years ago. If one figures a 10% inflation rate per year (probably low) this would be about \$11,000 per house at present costs.

Operation and Maintenance Experience

The City of Bethel, with help from IHS, set up piped water and sewer service charges of \$25 per house per month (flat rate) and \$4 per 1000 gal for commercial users to pay the operation and maintenance costs of the Bethel Heights facilities (no amortization or payback of original construction costs). Water is also hauled by truck from the pumphouse to the existing "downtown" area and honey bucket content are collected by tank trucks which pump the wastes in the sewage lagoon. The charges for these services were given earlier. After three years of operation the city raised the rates to \$35 per house per month and \$8 per 1000 gal to counteract increasing fuel and electrical costs and to overcome a deficit they had accrued. These higher charges are still lower than cities of comparable sizes and system types such as Nome, Kotzebue, etc. With the new rates, the utility operation is now in the black with several thousand dollars in their account.

The operation costs for the sewer system break down into essentially electrical costs as operating experience had shown that it is not necessary to add warm water at the end of the loop for circulation during period of low flow. The incoming sewage (to the holding tank) temperature seldom drops below 55°F even during periods of low water use. The water was being circulated at about 50°F and nearly all the houses have hot water heaters. The 1972 electrical costs (at average of 8¢/KWH) for the pump stations and sewage transfer pumps, etc. in the pumphouse (assume 20% of pumphouse electrical use) amounted to: (There are 12 pump stations to each electrically metered "bank").

USE	1972 Average Monthly Cost
Pumphouse (sewers)	\$ 138
Lift Stations on 1st	386
Lift Stations on 2nd	389
Lift Stations on West 3rd	329
Lift Stations on East 3rd	387
Total Average Monthly Electricity	\$ 1,629

The high electrical use months were January, February, and March while the low use months were July and August as would be expected. The electrical cost per pump station per month averages out at about \$35.

The routine maintenance costs specifically for the sewer system are more difficult to isolate from those of the entire system. Experience shows that it took one man full time to maintain the 48 lift stations. Assuming eight hours per day at \$10 per hour this amounts to \$1600/month. Parts for the pump stations, sewage pumps, etc. averaged about \$300. This adds up to a total operation and maintenance cost of about \$3530 per month for the Bethel Heights sewer system.

Considerable instrumentation was installed to measure the water's incoming and outgoing flow and temperature and incoming sewage temperatures. Thermocouples were installed on a typical section of the insulated lines (See Figure 7) to determine the effect on ground temperatures due to the water and sewer lines. Figure 8 shows the temperatures recorded for 1972 and estimates of the effect due to the pipelines.

IHS had to replace all the pump station control panels before the system could be placed in operation. This was necessary because moisture had corroded all the electrical contacts beyond cleaning. The contractor had set the stations in the ground during the fall of 1969 but did not start the dehumidifiers and heaters. The resultant moisture caused considerable damage. This has not been a problem since the system was placed in operation.

The Alaska State Housing Authority could not administer the project on the basis of home ownership as intended in the beginning because the occupants' incomes were too low to make the house payments when the limitation of a family not having to pay more than 1/4 of their income on house and utility payments was considered. Thus they essentially changed it into a rental project to make it pay. This change caused considerable more problems for the water and sewer facilities because there were many instances where families, etc. would come into Bethel for a month or so from outlying villages and rent a house. When they moved out, they would turn off the heat without considering the plumbing. This caused several complete freeze-ups of the house plumbing and caused glaciering problems in some house gravity sewer lines.

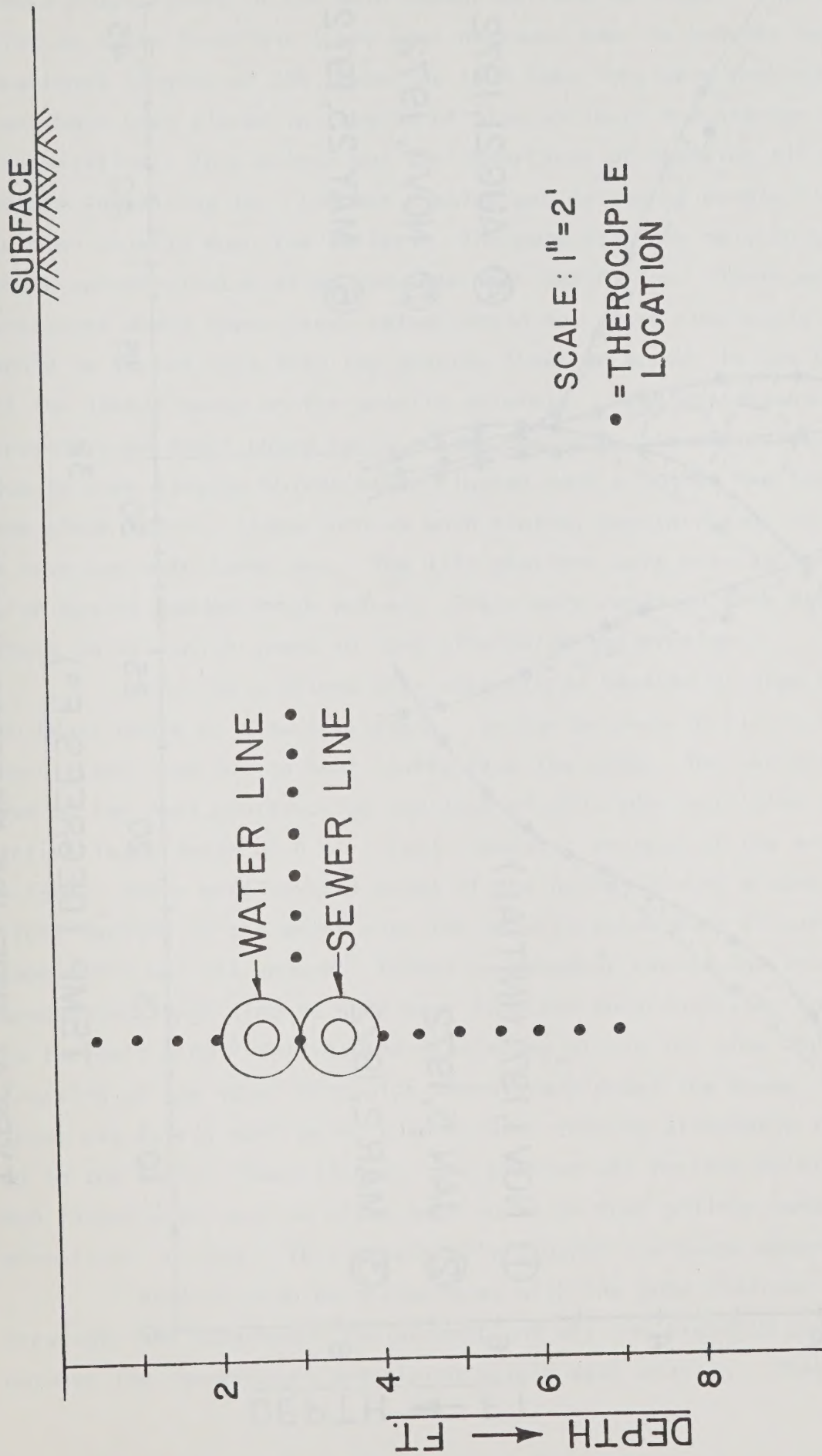
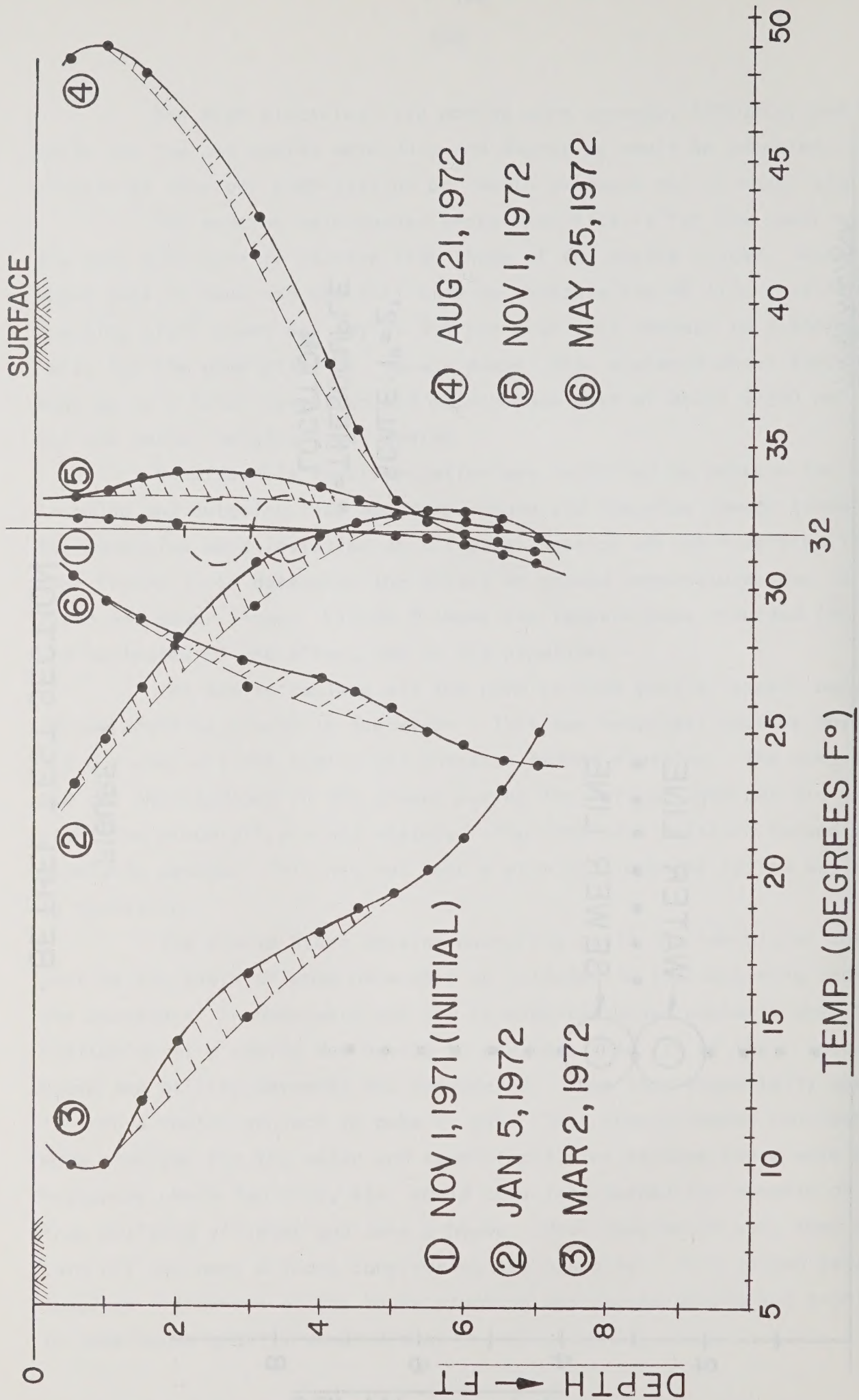


FIGURE 7
BETHEL TEST SECTION



TYPICAL PIPELINE EFFECTS ON SOIL TEMPERATURE - BETHEL

FIGURE 8

When the system was first started, there were three instances where plugs formed in the main sewage collection lines. Upon excavating at these locations (they were narrowed down to between two lift stations) lengths of 2X4 lumber up to 4 feet long were removed. They must have been placed in lengths of pipe while in the storage yard before installation. This points out the importance of checking all pipe before installing it. Another problem was caused by people flushing foreign objects down the toilets. The pump stations rely on the inlet check valves closing after the sump tank has filled. There were some instances where these check valves would not close completely and sewage would be forced back into the gravity lines to appear in the bathtub of the lowest house on the gravity mainfold. Needless to say this spawned some angry phone calls to the operator. In all cases it was due to some foreign object being flushed down a toilet and lodging in the check valve. Items such as wash cloths, sanitary napkins, and even a beer can were taken out. The lift stations were originally equipped with spring loaded check valves. There were replaced with weighted check valves which seems to have eliminated the problem.

Very few problems were encountered because of pipe movement due to frost heave or thaw settlement. As can be seen in Figure 8 there was hardly any thaw due to heat losses from the pipe. The surface damage due to the road construction and lack of drainage facilities created an active layer depth of 6 to 7 feet, however, instead of the anticipated 4 feet. There were several cases of the houses moving around due to frost heaving to the point even the service connection slippage allowed (about 8") was not enough. Excessive movement caused the insulation around the sewer line to pull away from the house exposing the bare pipe to the cold wind. This caused glaciating within the pipe and usually freezing of the sewer drop pipe immediately under the house. Thawing these was fairly easy using a warm water thawing attachment that bolts on to the toilet floor flange. The problem was further eliminated when HUD funded a project to place each house on four pilings sunk into the permafrost in 1973. This essentially stopped the house movement.

Another problem encountered with the pump stations was the breakage, and subsequent replacement, of all the flexible couplings between the compressors and piping within each station. They were

originally made of corrugated copper but most of them soon cracked because of vibration. They had to be replaced with short sections of rubber pressure hose.

Examination of the lines showed no deposition of grease or solids and thus the "poly-pigs" have never been sent through the lines. The manufacturer claims they will go through a half-closed gate valve and they are routinely used on oil lines. However, in trying to dewater a water transmission line at Kotzebue, IHS could not push one around a 90° elbow. With this experience we were reluctant to try them at Bethel unless it was absolutely necessary and unless a radio transmitter or something could be inserted in the "pig" so that, if it got stuck somewhere, it could be located and removed. Several letters to the manufacturer failed to bring any information as to methods of tracing them.

The water use and thus sewage contributed to the system varies from about 50 gpcd in the summer to 75 gpcd to 130 gpcd at times in the winter. The higher rate in the winter is due to people leaving faucets running to prevent house plumbing and water service lines from freezing during extremely cold weather.

The original electrical lines from the "bank" control points were laid with the pipes. This proved to be a problem, however, as anytime repairs or connections were made to the water lines, the electrical lines were damaged. They were transferred to overhead lines in 1972.

Recommended Changes in the System

The Bethel sewage collection and treatment facility has operated satisfactorily for four years. Last December the city power generation plant burned to the ground leaving the entire city plus Bethel Heights without electricity. Standby generating equipment sufficient to operate the pumphouse had been included in the IHS sanitation facilities project but could not be used to operate the pump stations because they were not wired so as to receive their power through the pumphouse. The entire city was declared a Federal Disaster Area and, as such, eligible for federal funds for emergency and long term repairs. They flew in two 900 KW generators from New Mexico and put them on line. This was emergency power only, as the power requirements for the entire area were about

2500 KW. When the emergency units were placed on line there were some severe voltage fluctuations which damaged the well pump, etc. Most of the water service lines in Bethel Heights froze which reduced the input of sewage to the gravity lines and caused considerable glaciering in those lines. Water will not be restored to the houses until next summer and the full extent of damage to the systems will not be known until then. Federal funds will be available to the city to repair the systems and several changes will be made to improve the reliability and decrease the operational and maintenance costs when the repairs are made. The changes in the sewerage collection system will be:

1. All pump stations will be wired back into a central control panel in the pumphouse. This will allow them to be operated using the pumphouse standby generator in the event of future power outages. It will also be easier to monitor problems in each using a central alarm panel. In case of malfunction, the panel has alarms, lights, and rings three different telephone numbers if no one is in the pumphouse. Poor reliability of "bush" electrical systems dictates complete standby capability for pumps and boilers used in water and sewer systems. Also, because of voltage fluctuations, high and low voltage protection should be built into all motor controls.
2. Pipe movement has been less than anticipated and it is felt that the number of pump stations could be reduced by extending the gravity lines further. This will probably necessitate some slightly shallower slopes (than the present 2%) and would require gravel bedding. If the number of pump stations can be reduced, it will reduce the operation and maintenance costs.
3. The trucks dumping honey bucket wastes at the sewage lagoon have caused some bank erosion which must be repaired. Also, much of the honey bucket wastes from the "downtown" area are picked up in plastic bags which are used to line the honey buckets. These tend to float and do not bio-degrade when they are dumped in the lagoon.

4. Although they won't be changed in the Bethel Heights system, in future systems, consideration will be given to using submersible pump type stations instead of the pneumatic ejector type to try and further reduce the operation and maintenance costs. This will be covered further in the following section.

PRESSURE SYSTEM CONSIDERATIONS FOR GALENA, ALASKA

Introduction

Galena is a Indian Community on the Yukon River in Central Alaska. The present town consists of about 100 houses on the bank of the river where flooding, due to ice jams, is a yearly problem. The community is receiving 40 new houses from HUD which they plan to place in a new area called Alexander Lake out of the flood plain. The area has been surveyed and laid out as shown in Figure 9. The new houses are now under construction with three or four houses already located in the area. IHS constructed a watering point with treatment facilities to remove about 40 ppm iron and the initial phase of a sewage lagoon to serve the present facilities during the summer of 1975. Water is presently hauled from the plant to the existing town as well as the occupied houses at the Alexander Lake site. In addition there is a health clinic connected by utilidor to the plant receiving water and sewer service. Plans call for water distribution and sewage collection lines to be extended to the individual houses in the Alexander Lake area and a new school with construction starting in the fall of 1976. The present sewage lagoon will be enlarged to treat all the sewage from the area. The soil conditions in the area rule out the possibility of buried lines and the topography is relatively flat making an above ground gravity sewage collection system impracticable. At this time, the possibility of a pressure sewer system is being investigated.

Preliminary Design Considerations

Present considerations call for individual pump-grinder units in each house or building which would pump into collection lines, through the pumphouse, to the lagoon. The collection lines would be located in

a small utilidor laid on the surface of the ground with a circulating water line and a standby, circulating glycol loop. Heat in the well insulated (3" urethane) utilidor (probably about 4'x12" inside dimensions) would normally be provided by heat loss from the circulating water lines or sewer lines, but the heated glycol would be circulated if thermostats indicated low temperatures in the utilidor, or if water circulation had to be stopped. The utilidors would be placed back away from the roads and pass close to or under the houses to reduce vehicle damage and to shorten or eliminate service lines everywhere possible. Service lines are a "weak link" in any arctic water or sewer system. The utilidors would have to be able to drain in case of a sewer line break to reduce the possibility of contaminating the water lines.

The most critical factor in the design will be the pump-grinder units. The following design factors will be considered and/or included:

1. Each pump-grinder will be provided with a 100% standby unit mounted in the same sump and "on line" so, if the initial one fails to start, a further rise in the sewage level in the sump will set off an alarm and start the standby unit. (Similar to Model GP 214 by Environment-One.) (See Figure 10.)
2. The grinder unit will grind up all materials capable of being flushed down the toilets to 1/4" maximum before they enter the positive displacement pump. A positive displacement pump is necessary because their pumping rate is only slightly affected over a large range of heads. Also, this type of pump requires a lower power input to purge the system of air pockets which could form. It is difficult to estimate how many of the pumps will operate at the same time, but they can take a 40% (or higher) overload for short lengths of time so, even if a larger number than anticipated pump at once, no damage will be done. They are designed to operate at 35 psi discharge head but can handle 50 psi without harm.
3. The entire pump-grinder unit can be removed from the sump quite easily by two men (weighs about 150 lb) in a few minutes for cleaning or repair. Past experience and studies

by the U.S. Environmental Protection Agency (EPA) have shown a greatly improved reliability for these units. One set of tests made in Albany, N.Y. gave a "down time" of only 0.25% on 12 units operating for a year. The first installations several years ago experienced two main problems. One was grease plugging up the pressure sensing line and the other was the pump losing its prime. The new units have been designed to completely eliminate both of these problems.

The EPA tests indicated the one horsepower pumps operated 2.6 times per day per person with each period of operation lasting from 50 to 70 seconds. The water use rate in the test was only 35 gpcd. Using a figure of 70 gpcd (which should be high especially if low water use fixtures are used and service lines can be eliminated and the practice of wasting water to keep service lines open correspondingly reduced), a five person family would utilize 0.32 KWH a day for the unit. Even at 25¢/KWH this is an electrical cost of only \$2.40 per family per month. This should be about the entire energy cost of the sewage collection system.

4. The sump is designed so the pump cleans it by scouring as it pumps. Setting of solids and grease deposition has not been a problem in existing installations.

Exit check valves should be located on horizontal runs so solids do not settle on them while the pump is not in operation. Also, two check valves should be used as a safety factor even through experience to date does not dictate this need. Pressure sensors should be used to control the pumps and alarms as rags, toilet paper, etc. tend to foul float switches.

5. In case of a power outage, the sump (at least 120 gal) should supply several hours of storage if water use is curtailed.
6. The pump-grinder units would be supplied with low voltage protection and a relay that would temporarily reverse the

rotation of the pump and grinder to prevent damaging the motor if a piece of glass or metal were to bind in the grinder.

7. The sumps would be of fibreglass construction (corrosion problems have been encountered with steel) and insulated with 3 to 4 inches of urethane on the outside. The would be placed in or under the houses with the top flush with the floor so all fixtures would drain to it by gravity.

The pressure lines leaving the pump-grinder unit would be 1 1/4" PVC. The lines in the utilidor would be manifolded according to the number of units on the branch and the number of those expected to be in operation at one time (see curve in Figure 10). The collection line velocity must be greater than 3 feet/second at some time each day to stop grease accumulation on the upper part of the pipe. It is actually better to have them slightly undersized than oversized. The test installation showed that only 3 pumps out of 12 (25%) operated at the same time and even this number very seldom. The more pumps on a line the lower this percentage would be.

It is also recommended that air release valves be installed at the major high points in the lines. This could be done inside the utilidor. It may be necessary to supply a flushing tank at the end of each branch, not for heat purposes in the utilidor, but for occasional flushing at the required 3 feet/second.

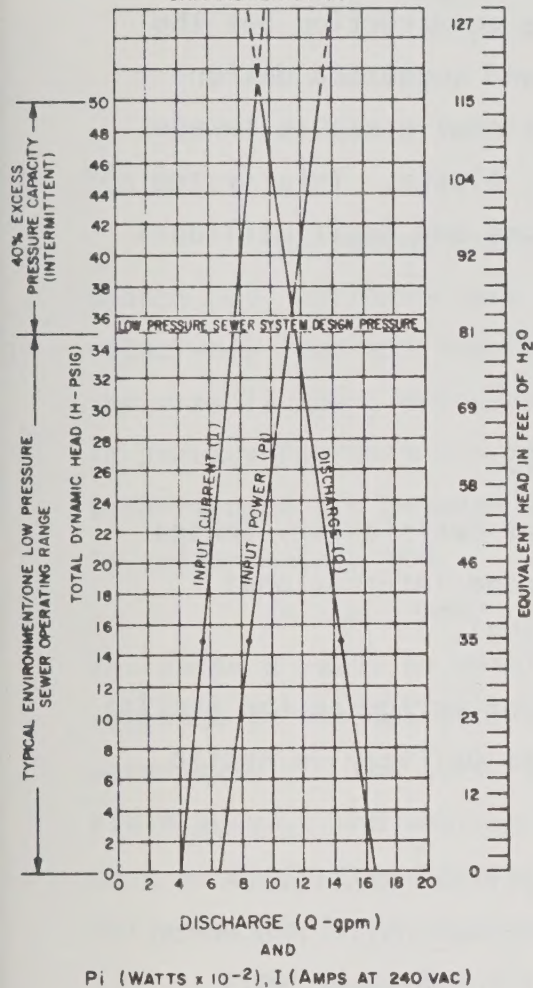
SUMMARY

It is important to consider alternates to a conventional gravity sewer system in arctic areas, especially where pipelines cannot be buried. The alternates must be considered on the basis of their operation and maintenance costs as well as initial construction costs.

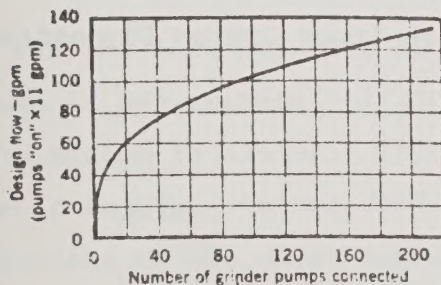
An extensive utilidor system can be a psychological as well as physical barrier in a community. A pressure sewage collection system allows us to use a small, inconspicuous, ground level utilidor going from building to building instead of a large structure up off the ground on piling that acts as "fences" throughout the community and creates traffic problems for vehicles and people. These utilidors can be small

GRINDER PUMP

TYPICAL PERFORMANCE CHARACTERISTICS

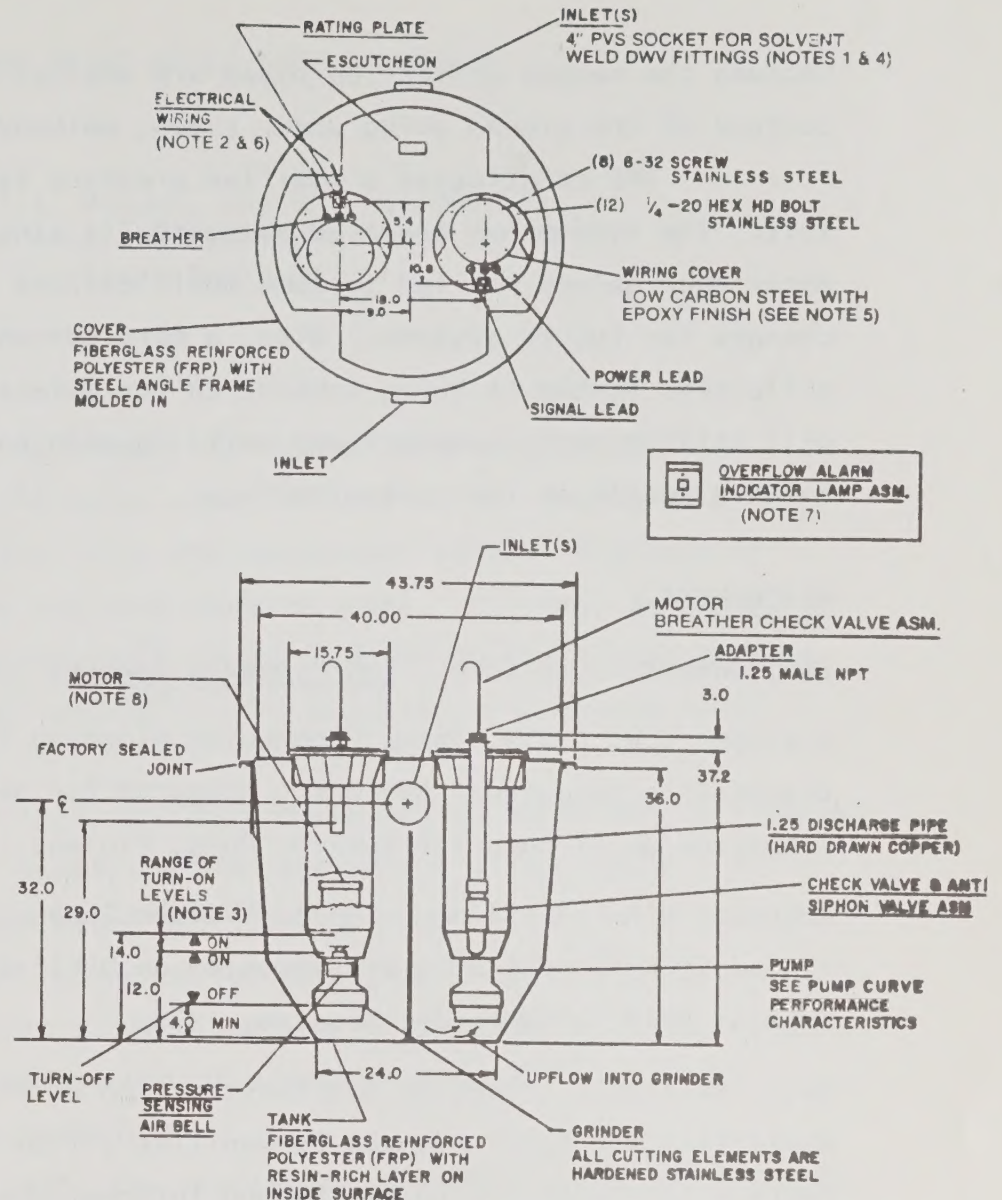


(B)



How big should a pressure-sewer main be? Clearly, that depends on the expected flow, which in turn depends on the number of grinder pumps tying into the main and the number of expected simultaneous operations.

(C)



NOTES:

1. CAN BE ADAPTED TO ANY SYSTEM OF DWV PIPING DICTATED BY LOCAL CODES INCLUDING CAST IRON, COPPER AND NON-METALLICS.
2. USE FITTINGS APPROPRIATE FOR WIRING MATERIAL WHICH SHOULD BE PER APPLICABLE CODES. ALL FITTINGS MUST BE WATER-TIGHT.
3. EXACT TURN-ON LEVEL DEPENDS ON IN-FLOW RATE DURING TIME DELAY INTERVAL AFTER PRESSURE SWITCH CLOSURE.
4. INTERIOR OF TANK (WET WELL) IS VENTED THROUGH INLET DRAINAGE PIPING.
5. COVER IS SUITABLY GASKETED AND BOLTED IN ORDER TO MAKE WEATHER TIGHT.
6. TEN FEET OF TYPE UF CABLE, PREWIRED AND CONNECTED WITH WATER-TIGHT WIRING CONNECTORS, PROVIDED FOR BOTH POWER AND SIGNAL CONNECTIONS. OTHER LENGTHS OF MATERIALS AVAILABLE ON SPECIAL ORDER. SEE NOTE 2.
7. OVERFLOW ALARM INDICATOR LAMP ASSEMBLY FURNISHED ON WALL PLATE 2-3/4 X 4-1/2 INCHES. FITS STANDARD WALL BOX (BY OTHERS). INSTALL AT MOST OBVIOUS LOCATION ON PREMISES AND CONNECT PER WIRING DIAGRAM IN INSTALLATION INSTRUCTIONS. AUDIBLE ALARM (NOT FURNISHED) MAY BE PARALLELED WITH CIRCUIT. LAMP SIGNAL CIRCUIT CONTACT RATING IS 15 AMP AT 120 VAC OR 1/2 HP AT 120/240 VAC.
8. ONE HORSEPOWER, SINGLE PHASE, CAPACITOR-START, INDUCTION MOTOR WITH INTEGRAL AUTOMATIC RESET THERMAL OVERLOAD PROTECTION. 240 VOLT, 60 HERTZ, STANDARD. 120 VOLT, 60 HERTZ AVAILABLE.
9. ALL DIMENSIONS ARE IN INCHES. DO NOT SCALE DRAWING.
10. EXACT DETAILS OF DIMENSIONS AND SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE.

(A)

FIGURE 10 PUMP-GRINDER CHARACTERISTICS

because the sewage collection pipes are smaller and they can follow the contour of the ground going under roads, walkways, etc. in culverts.

IHS constructed a modified pressure system at Bethel, Alaska in 1971. The system has operated successfully since construction but the experience gained has led to some modifications and suggested design changes for future systems. Also, a more conventional pressure sewage collection system is being considered for Galena, Alaska. This system will utilize small pump-grinder units in each house and small utilidors lying directly on the tundra surface.

REFERENCES

Environmental One Corp., Low Pressure Sewers, 1975.

Grainge, J.W. & J.W. Shaw, "Community Planning for Satisfactory Sewage Disposal in Permafrost Regions", prepared for Second International Symposium on Circumpolar Health, Oulu, Finland, 1971.

Rogness, D.R. & William L. Ryan, "Vacuum Sewage Collection in the Arctic: A Case Study", presented at Symposium on Utilities Delivery in Arctic Regions held in Edmonton, Alberta, 1976.

Ryan, William L., "Design and Construction of Practical Sanitation Facilities for Small Alaskan Communities", from Permafrost: The North American Constitution to the Second International Conference, 1973.

Ryan, William L., "Effectiveness of Urethane Pipe Insulation in the Arctic Environment", Unpublished, 1970.

U.S. Environmental Protection Agency, "A Pressure Sewer System Demonstration", EPA-RZ-72-091, Nov. 12.

THE ESKIMO POINT WATER SUPPLY PROGRAM

by

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PART I

The Eskimo Point settlement is located on the west shore of Hudson Bay, approximately 165 miles north of Churchill. The terrain is relatively flat and low-lying, with the occasional esker. Drainage in the area is poor, and there are many shallow lakes. The mean temperatures in January-February are in the -25°F range, and during mid-summer average temperatures are between 40° and 60°F . The population of Eskimo Point is approximately 900.

In the summer of 1973, the Government of the Northwest Territories initiated a study on water supply for the Eskimo Point settlement, in response to serious problems being experienced with the Community's water supply. The terms of reference for the study were "to conduct field surveys and engineering studies leading to the selection of the most economical and practical method of providing Eskimo Point with a reliable supply of potable water".

In September of 1973, the settlement of Eskimo Point was visited by the authors, the first of many visits. The purpose of the trip was to make an on-site assessment of the water supply situation.

At the time of the initial site visit, water was being drawn from a shallow lake adjacent to the settlement. The maximum depth of this lake is approximately 2' to $2\frac{1}{2}'$, and therefore, the lake freezes to the bottom in winter. This was the normal source of the settlement's water supply. In the fall of each year, an earthfill-type reservoir adjacent to the water supply lake was filled to provide winter water supply. Local distribution was and still is by tracked tanker vehicle. Due to the poor quality of the water in the reservoir, residents of the settlement usually obtained drinking water on an individual basis by cutting ice from nearby lakes.

Based on general observations, discussions with local residents, and recorded water quality tests, the problems associated with the existing water supply system in Eskimo Point in 1973 could be summarized as follows:

1. The existing water reservoir could not be used during the summer due to high turbidity, caused primarily by wave action against the silty embankments.
2. Because the water supply lake and the reservoir were situated immediately adjacent to the settlement, the probability of pollution was high. Cases of minor stomach disorders, allegedly attributable to the water supply, were not uncommon. Total coliform organisms in excess of 1,500 MPN/100 ml had been recorded in the supply.
3. In the reservoir, during the winter months, iron concentrations in excess of 10 times recognized acceptable limits had been recorded. Based on five separate samples over a five month period, the true color exceeded recognized limits by more than 300%.
4. The capacity of the reservoir was inadequate for existing needs at the time of the study.

Needless to say, the water supply situation at Eskimo Point in 1973 was unsatisfactory, and improvements were urgently required. Turbidity, high dissolved solids, bacteriological contamination, and inadequate capacity all combined to make the existing system virtually unuseable.

As a first step in considering an improved water supply for Eskimo Point, the required quantity of water was estimated, based on a projected population of 1,300. This projection represented an approximate 100% increase in population over a time period in the order of 15 years. (The Department of Local Government had established quotas for water management in northern settlements. The quota, where water was delivered by vehicle, was 800 gallons per household per month. At the design population of 1,300, the maximum water consumption with vehicular delivery would be 8,500 gallons per day. For any water supply scheme involving storage, the design storage period would have to be in the order of 8 months.)

During the site visit, and in subsequent analysis of the field data, a number of potential sources of water were considered:

- a. The lake which was in use in 1973 was certainly the most convenient source of water at Eskimo Point. However, due to the various pollutants present, this water source would require modifications to the lake and/or treatment of the water.
- b. A number of small lakes are located at varying distances from the settlement. Soundings were taken to determine depths. None of the lakes exceeded $3\frac{1}{2}'$ in depth, and therefore, all would almost certainly freeze to the bottom in winter, or to such an extent as to be unuseable. Any water supply scheme utilizing the shallow lakes adjacent to the settlement as a source of water must also include deep supplementary storage.
- c. A large and deep lake is located approximately 9 miles from the settlement. Discussions with local residents and chemical analysis of a water sample indicated that the water was of acceptable quality.
- d. Sea water was of course considered as a potential source of potable water supply.

A number of water supply and storage systems were considered in detail, generally as follows:

1. Improvement of the existing system:

In order to use the existing reservoir, the problems of inadequate capacity, turbidity, and bacteriological pollution would have to be overcome. Essential major improvements would include enlargement of the reservoir, lining of the reservoir to remove turbidity and eliminate seepage, strict control of access to the reservoir to control bacteriological pollution, and development of a suitable source of water for replenishing the reservoir.

Enlargement of the reservoir would have involved re-excavating and re-shaping the reservoir, and raising the berms by approximately 4 feet. Soils at the site of the existing reservoir are comprised mainly of saturated silty material, and construction difficulties were anticipated - particularly if the work was undertaken in the summer months. It may have been possible only to work on the material when frozen.

It was considered necessary to line the refurbished reservoir with an impermeable membrane, in order to eliminate turbidity, and prevent seepage losses. Control of access would have been accomplished by improving the method of drawing water from the reservoir to eliminate the introduction of pollutants, and through the construction of a fence around the outside of the berms.

The development of a suitable water supply source for use in conjunction with an improved reservoir required special consideration. The lake providing the water supply source was polluted. Either the existing water supply lake would be used and the water treated or, alternatively, a "summer-only" pipeline could be constructed to a new source. It was decided that ultimately the water supply should be from an unpolluted lake located further from the settlement.

2. New Reservoir:

An entirely new earthfill-type reservoir, located somewhat further from the settlement than the existing reservoir but still within easy range of tracked water supply vehicles, was considered as an alternative to repairing the existing reservoir. There is no impervious material available at the site suitable for reservoir construction. A new reservoir would have to be constructed from granular material excavated from adjacent eskers, and an impervious liner would be required.

Two alternate methods of construction were considered:

- a) The balanced approach, utilizing material excavated from the bottom of the reservoir to construct the berms. Cut and fill would be balanced, and therefore excavation minimized. Using this method, it was estimated that approximately 30,000 cu yd of material would have to be excavated.
- b) The unbalanced, or "fill" approach. Alternatively, the reservoir could be constructed by building the berms from the material most readily available, with little excavation inside the berms. Construction of the reservoir using this method would have entailed the moving of approximately 40,000 cu yd of fill.

While this method required more excavation, the material would be less costly to excavate through the judicious selection of borrow areas and the avoidance of deep cuts in permafrost.

Also, constructing the reservoir by the "balanced" method would result in a large portion of the reservoir storage being below natural grade. Effective control of potential hydrostatic up-lift pressures on a liner would be difficult. By constructing the reservoir with most of the storage volume above natural grade, it was anticipated that no serious groundwater problems would be encountered. In addition, it was considered desirable to utilize an existing fill (associated with an airstrip in the process of being phased out) as one of the berms for the new reservoir.

The new reservoir alternative would include a summer supply pipeline to convey water to the reservoir from adjacent lakes, and a pumping facility for filling the water distribution vehicles.

The critical item associated with the construction of a new reservoir would be the selection and placement of an impermeable liner. There are various types of membrane liners, some of which are not applicable for arctic installations. Durability, ease of installation, and cost are the major concerns when selecting a membrane liner.

Two types of liners are in fairly widespread use and were considered suitable for use at Eskimo Point. Polyethylene membranes have been used for lining reservoirs with varying degrees of success. Initial failures have been attributed mainly to poor jointing techniques, and damage due to excessive sunlight exposure. Heat fusion joints and pigmentation of the membrane have largely eliminated these initial problems. There are conflicting reports as to the suitability of polyethylene for northern applications. Russian researchers speak highly of polyethylene, particularly with regard to its chemical inertness and resistance to frost action. There are several successful installations in southern Canada, but to the best of our knowledge, there are no North America applications under severe arctic conditions.

The alternate type of liner under consideration was hypalon membrane. Hypalon is manufactured in bulk by Du Pont of Canada Ltd. The raw material is processed into membranes by a number of different companies who distribute the finished product under a variety of trade names, e.g., Dunseal Membrane manufactured by Dunline Ltd. It is understood that membrane processing may involve a variety of chemical treatments, such that the products of different companies may vary somewhat in properties. A shrinkage of approximately 5 percent in the liner is experienced after installation and is referred to as "curing" of the membrane. The material is rated for -85°F service, and uses a solvent sealing method for jointing. There are existing installations in arctic regions which are reportedly satisfactory.

In comparing alternative membrane liners, the lack of experience with polyethylene, installed under arctic conditions, was of concern. Hypalon liners, on the other hand, apparently have proved to be successful - at least for short trial periods - under arctic conditions, and appeared to have superior physical properties as related to cold weather installation. During the design phase of the project, a number of physical tests were carried out by the consultants under laboratory simulated cold weather conditions, in order to prove or disprove the claims of various suppliers and manufacturers. Testing procedures, a thorough review of the available technical data, and information gathered from personal contacts with persons who had been involved in the installation of liners under cold weather conditions eventually resulted in the selection of a hypalon-based product (as will be discussed in more detail in a subsequent part of the paper).

A potential problem associated with the installation of a membrane liner in a storage reservoir related to hydrostatic uplift; i.e., the uplifting force caused by groundwater pressure on the underside of the membrane. As long as the membrane is surcharged with a dead weight greater than the potential hydrostatic groundwater pressure, the membrane will not move. At Eskimo Point the "unbalanced", or "fill" approach to construction of the reservoir would eliminate this problem; insurance was provided through the installation of perforated drains under the liner.

The installation of a membrane liner also requires that special consideration be given to protection against ice damage. Sufficient material would have to be placed over the liner to provide the necessary protection.

3. Dam Construction:

The natural drainage pattern adjacent to the settlement indicated a possible dam site between two eskers. Construction of a dam approximately 20' high and 1,800' long would form a reservoir of sufficient area and depth for a year-round water supply.

The general problem of earthfill dam construction in the far north utilizing pervious and semi-pervious material is complex. Although earthfill dams can and have been successfully constructed on permafrost, dam and spillway failures are not uncommon. The main area of concern is the establishment of a safe and reasonably water-tight structure utilizing local impermeable soils. It is particularly important to investigate the possibility of "piping." In order to prevent piping, a carefully graded drainage blanket or filter must be provided at the point of egress of seepage water (suitable materials would be difficult to obtain and place in a location such as Eskimo Point) or the length of the path of percolation through the dam may be increased by enlarging the cross-section of the embankment, or through the use of impervious aprons or cutoff walls.

The complete freezing of an earthfill dam up to the high water level in the reservoir would, in effect, create an impervious cutoff wall. There is, however, no assurance that the core of an earthfill dam constructed at a site such as Eskimo Point would freeze to a solid mass without seepage zones, unless special measures were taken to ensure that the core of the dam became completely and permanently frozen. Pervious dams subjected to water seepage normally assume in a short period of time a temperature only slightly less than that of the reservoir water. The complete freezing of an earthfill dam might be insured through the installation of refrigeration ducts in the dam. The Soviets have used this approach on a number of dams.

Naturally, the installation of refrigerating equipment and the operating and maintenance costs associated with such equipment would add considerably to the total cost of dam construction.

In addition to the dam itself, a major area of concern would be the spillway. The site material at Eskimo Point is highly erodible, and the entire spillway area of a dam would require protection against erosion. The spillway would require heavy rip-rapping, or alternatively, concrete or metal channels and discharge aprons.

4. Desalinization:

Desalinization of sea water would be a solution to the water supply problem at Eskimo Point. Two methods of desalinization were considered: reverse osmosis and multi-stage flash distillation. In 1973, reverse osmosis was a relatively new development in the water treatment field. The process is still primarily used to treat waters which are too high in mineral content to be treated by conventional methods, i.e., brackish water, and the process is not generally utilized for desalting sea water, although intensive research and development work is being carried out in this field at the present time.

Desalinization through the process of multi-stage distillation is an established method of desalting sea water, and the process could have been utilized at Eskimo Point. The desalinization unit would be a "package" type with all components pre-assembled. The unit would be self-contained and automatic in operation. The unit compresses steam from boiling sea water, thereby raising its temperature. The compressed steam is then discharged back to the heating element of the still and gives up its higher heat - thus maintaining the boiling - and simultaneously condenses and is collected as pure water.

5. Vehicular delivery from a lake of sufficient depth to provide a year-round water supply.

Consideration was given to constructing a roadway to a lake 9 miles away from the settlement. The terrain to be traversed was difficult. Two major creek crossings would have been required, and steep grades negotiated at a number of locations. One of the major disadvantages associated with this alternative is the high cost of operating the

delivery system. Operating costs for a vehicular delivery system to the lake 9 miles distant from the settlement were estimated in excess of \$100,000 per year, at the design water consumption.

6. Pipeline Supply:

The installation of a pipeline from the distant lake to the settlement was also considered. Line heating and/or recirculation would be required in order to keep the system from freezing. The cost of these measures made the operating costs of the system prohibitive. Hydraulic considerations would dictate a large diameter of pipe or a series of pumping stations.

The installation of a pipeline from the lake 9 miles distant from the settlement was considered only as a "long-term" solution, long-term referring to the time when a pressure water distribution system, (i.e., a conventional municipal water supply system) would be considered for the settlement. Construction costs would be in the order of \$3,000,000 in 1973 dollars.

A detailed cost comparison of the various alternatives outlined above indicated that the rebuilding of the existing reservoir would be the most economical solution to the problem. In completing the study, however, it became evident that the decision as to the best alternative should not rest solely on engineering and economic considerations. In the opinion of the consultants, subjective considerations had to be taken into account, particularly with regard to the nature and direction of the future development of the settlement, and the preferences of the local inhabitants. Meetings were held to discuss the matter with representatives of the Department of Public Works of the Northwest Territories Government, and with the Eskimo Point Settlement Council.

The final choice appeared to lie between renovating and enlarging the existing reservoir, and constructing a new reservoir. The advantages and disadvantages to each approach were as follows:

A) Improve existing reservoir.

Advantages:

1. Lower cost.
2. Convenient location with respect to delivery system.

Disadvantages:

1. Too close to the settlement with respect to control of pollution.
2. Too distant from satisfactory source of supply
3. Difficult soil conditions for construction.
4. Uplifting of membrane liner due to hydrostatic pressure would be a potential problem.
5. May restrict settlement expansion.

B. New reservoir.

Advantages:

1. Close to source of satisfactory water supply.
2. More stable soil conditions.
3. Potential uplifting of liner less of a problem with the reservoir judiciously located and constructed.
4. More removed from sources of pollution.

Disadvantages:

1. Higher cost.
2. Less convenient with respect to delivery system.

On the basis of an overall evaluation of the advantages and disadvantages of the alternatives, the consultants favoured the construction of a new reservoir.

A meeting with the Council of the Settlement of Eskimo Point was held on June 13, 1974, at which a recommended program was presented by the consultants, involving the upgrading of the water supply system at Eskimo Point through the construction of a new reservoir. The program was found to be acceptable to both Government and the local Council.

The final recommended program was as follows:

1. The "new reservoir" alternative would be implemented. The new reservoir would be constructed adjacent to the existing airstrip west of the Community.
2. A detailed hydrological analysis of the drainage basin would be carried out to confirm total recharge capacity of the watershed area.

3. Additional soundings would be taken in lakes near the proposed reservoir site in order to establish the various potential sources of water supply. In addition, the quality of the sources would be evaluated.
4. Soils consultants would be retained to undertake a detailed investigation in the vicinity of the proposed location for the reservoir, in co-operation with the prime consultant's personnel, to identify, survey and mark out an exact reservoir site and to identify, survey and mark out borrow areas. The detailed design of the reservoir and the fill and draw system would be carried out. The prime consultant would investigate equipment types and logistics of equipment supply and set up a construction program to commence mid-summer of 1974 and terminate with the completion of the project the fall of 1975.
5. It was recommended the reservoir be designed for 2,000,000 gallons storage below ice, corresponding to the estimated eight months water consumption of the settlement, based on a future population of 1,300 and vehicular distribution.

Part II

Hydrological Analysis

In July 1974, W.L. Wardrop & Associates Ltd., the prime consultant, engaged the service of a hydrologist to study the recharge ability of the potential water sources west of the settlement.

Using stream flow records and climatic data from weather stations in the area, the hydrologist estimated that a low value of the ratio of annual cycle of runoff to the concurrent November to October precipitation from 29 years of record at Chesterfield Inlet was 5.4 inches. (Detailed information was not available for Eskimo Point; therefore, Chesterfield Inlet located 175 miles north was used, as climatic conditions are very similar.) The values indicated that a minimum annual yield of 2,000,000 gallons could be obtained from approximately 50 acres. The area tributary to the group of lakes lying west of the community of Eskimo Point greatly exceeded 50 acres.

Considerable variation in the ratio of annual runoff to precipitation may be anticipated, probably due to differences in the depth and development timing of the active layer from year to year. Values from 0.35 to 1.25 were observed from the data analyzed.

Some consideration was given to the potential ponds from which water would be pumped and the timing of pumping. Pumping early in the season may be preferable as this would allow the pond to refill from runoff and active layer discharge before freeze-up. Probably the supply pond area should be at least 70 acres to avoid quality problems that might arise from excessive drawdown.

Site Survey

The exact location of the new reservoir was selected in the field. A base line was established along the edge of the existing airstrip to be used for survey reference throughout the project. Detailed profiles were taken perpendicular to the base line such that a comprehensive grid of the area would be available for detailed design and construction control.

Lake Soundings

In conjunction with the detailed site surveys, more detailed lake soundings were taken of two potentially suitable supply lakes west of the community. On the basis of relative size and depth, a large body of water approximately two miles west of the community or one mile west of the proposed new reservoir site was determined to be the most acceptable water source. Final selection of the supply lake would then depend on water quality.

Water Quality

Chemical analyses of water samples taken in late 1974 were not considered sufficient or conclusive to justify a permanent pipeline installation. Although it appeared that the lake mentioned above would probably be selected, it was considered desirable to have the option open to change to a more suitable lake, if one could be found. In order not to jeopardize the program a portable pipeline and pump was recommended to be incorporated into the design of the new reservoir.

Geotechnical Evaluation

In late 1974, W.L. Wardrop & Associates Ltd. engaged the services of EBA Engineering Consultants Ltd. (who were involved in the original engineering study) to investigate the following additional items:

- the design of stable dyke configurations, incorporating a hypalon membrane liner; and,
- the selection of suitable construction materials and construction methods to be adopted, in view of the limited processing facilities.

The evaluation assumed an impervious liner consisting of a 30 mil (0.030 inch thick) hypalon synthetic rubber membrane would be used to line the reservoir. Clean granular fill material would be placed on the inside slopes and top of the dykes to protect the liner from ice and wind action.

As part of the original study carried out by EBA Engineering Consultants Ltd., a number of test pits were excavated in the general area of the reservoir site to investigate the subsurface conditions. The test pits encountered approximately 6 inches of bouldery, peaty topsoil, generally overlying about 12 inches of sandy gravel, in turn overlying a gravelly, silty sand. The test pits generally encountered seepage and sloughing conditions below a depth of 1.5 feet. Permafrost was encountered in only one test pit, at 2.8 feet below surface. The other test pits were excavated to 4 feet below ground surface.

The airstrip is situated on a linear, east-west running esker. Excavations in the esker, west of the airstrip, indicated that it consists of sandy gravels with cobbles and boulders and could form a ready source of borrow materials for the main dyke construction.

Observations at the site indicated that the slopes on the "airstrip esker", which rises approximately 15 feet above the surrounding terrain, lie at stable angles of about 30° . A number of tests, carried out in the laboratory, on samples of aggregate from the site, showed natural angles of repose ranging between 32° and 37° . From the point of view of construction of the main dykes, it was considered that two horizontal to one vertical slopes (26.5°) would be stable.

After constructing the main dykes and installing the liner, the interior berms would then be built up. The design and stability of these berms is more critical. As a starting point, it was assumed that the inside face of the berms should be placed at no steeper slope than three horizontal to one vertical (18.5°). It was considered that steeper slopes would erode and flatten under the effects of ice, wave and current action. This maximum recommended slope angle was based on visual experience rather than any quantitative analysis. For this reason, it was recommended that the reservoir be inspected annually, after thawing of the surface ice. This will be particularly important in the initial years of reservoir operation, when the performance of the interior berms under the action of erosional forces may be assessed.

In order to analyze the stability of the interior berms, it was necessary to know the angle of adhesion that could be mobilized between the fill material and the membrane liner. A series of tests were carried out in the laboratory using Eskimo Point soil samples and a sample of hypalon to ascertain the angle of adhesion. Tests were performed by measuring the resistance to sliding of a box filled with the sample and loaded in various increments, to a maximum of about 110 pounds per square foot. Tests were performed both with the membrane on a flat, hard surface and with the membrane underlain by sandy material. The results of nine tests indicated angles of adhesion ranging between 21° (dry, coarse, sandy gravel on hard base) and 32.5° (moist, fine to medium sand on the sand base).

From these results, an angle of adhesion of 20° between the interior dyke fill and the liner was adopted for stability analysis. It was also assumed that the width of the interior berm at the crest of the dyke will be 10 feet. The first dyke configuration analyzed consisted of the liner placed on a 2 to 1 slope and the inside face of the berm at a 3 to 1 slope. In a moist, as-constructed condition, the berm would be stable with a factor of safety of about 2 against sliding. The reservoir containing water represented a more stable condition, with a factor of safety in excess of 3. A check for the rapid drawdown condition, assuming a piezometric elevation coinciding with the face of the slope, was undertaken and indicated an unstable condition. This type of calcula-

tion is usually carried out in connection with the design of impervious earth dams. The validity of this type of calculation here is somewhat hypothetical, in that, it is unlikely that the assumed pore water condition would occur if the berms were constructed of free draining granular material.

The second configuration analyzed consisted of the liner laid on a slope of 3 to 1 with the face of the berm also at a 3 to 1 slope. In this case the stability of the moist fill could be represented by a factor of safety in excess of 3. Considering a similar drawdown condition as before the berm would still be stable with a factor of safety of 1.2.

Both dyke configurations would require the same quantity of fill; however, the second design would require approximately 35 percent less fill for the interior berms and a slight reduction in the quantity of liner required. The reduction in fill was considered significant, in that placing fill on the liner is a somewhat delicate operation and that, the type of fill required could be in short supply.

Alternative dyke configurations consisting of stepped berms and toe loads were investigated but not pursued, since it was considered that these offered less economic solutions.

It was decided that the following features be incorporated into the design of the reservoir dykes.

1. Three basic types of fill material would be required for constructing the reservoir:

- a) Main Dykes: (Class I)

Granular material regardless of particle size would be suitable. However, it was recommended that material showing the best available grading be used, since no positive compaction would be available at the site.

- b) Bedding Layer: (Class II)

A layer of finer material (silty sand or sand) should be provided on the inside slopes of the main dyke and on the base of the reservoir to act as a bedding layer for the liner. It was recommended that the bedding layer on the slopes be at least 2 feet thick (measured perpendicular to the slope) and at least 0.5 feet thick

on the base of the reservoir. The thickness of 2 feet recommended for the slopes was based on a practical construction point of view rather than a liner performance requirement. The sand material should be free of gravel and boulders. Occasional cobbles in excess of 1 inch should be raked off the surface. Final subgrade preparation specifications for the liner bedding layer should be checked with the liner manufacturer.

c. Interior Berms: (Class III)

Clean granular material would be required for the berms to avoid turbidity in the stored water. It was recommended that finer material (sand and fine gravel sizes) be used throughout, to conform to the liner bedding specifications. If coarse material was used it would be necessary to include a second, upper bedding layer to protect the liner.

2. "Tucks", running in both directions, should be left in the liner to allow for settlement and shrinkage. Settlements due to consolidation of the dyke fill material and to re-adjustment of the permafrost regime (assuming a 20 foot dyke) would be about 1.5 feet.
3. The crest of the main dyke should be at least 12 feet wide. Placing the interior berm fill would be a delicate operation if the liner was not to be damaged. A 10 foot berm width was considered a minimum for operating equipment. Wider berms could be used without adversely affecting the stability. The berms should be built up in 9 to 12 inch lifts. End dumping from the crest of the dyke was not recommended.
4. Prior to commencing construction, it was recommended that the survey of borrow sources be undertaken to ensure that the three basic material types would be available, to ensure that the most suitable materials in the area would be used and to estimate the quantities available. The preliminary studies indicated that all three materials were available; however, sampling of the esker at a number of different locations would indicate the better borrow areas.

Evaluation of Hypalon Membrane Liner

In addition to the geotechnical evaluation, W.L. Wardrop & Associates Ltd. took advantage of the laboratory services of EBA Engineering Consultants Ltd. to evaluate the suitability of hypalon as a reservoir liner under extreme cold weather applications anticipated at Eskimo Point.

It was established that the membrane liner would be required to operate under a freezing index for Eskimo Point of 7500 degree-days. (Freezing index taken from H.H. Thompson, 1963, First International Permafrost Conference).

A review of the A.S.T.M. Standards, Parts 37 and 38, dealing with testing of rubber and rubber products, was undertaken to ascertain tests that might be relevant to the Eskimo Point Reservoir application. The following standards were noted as being relevant.

a. D-2136 - Low Temperature Bend Test

4 inch by 1 inch samples of the rubber are placed in a hinged bending jig. The jig is allowed to swing closed, folding the sample through 180 degrees. The sample should be examined with a 5x magnifier and any fractures or cracks noted. Three tests should be performed at each temperature increment.

b. D-832-Conditioning of Elastomeric Materials for Low Temperature Testing

This standard presents a general discussion on the effects of low temperatures on rubber materials, dealing with simple temperature effects, vitrification and crystallization. Guidelines are given on the temperatures and time periods that tests should be carried out at, and gives details of various low temperature test cabinets.

c. D-1329-Evaluating Low Temperature Characteristics of Rubber Materials by a Temperature Retraction Test

In this test a sample is stretched, locked in the stretched condition, cooled to a non-elastic state and then released while allowing the temperature to increase. The temperatures corresponding to percentage retraction values of 10 and 70 percent are noted and correlate with brittleness and compression set, respectively.

d. D-2137-Low Temperature Impact Test for Brittleness Determination

The specimen is cantilivered from a jig and acted on by a falling weight. This test is not really applicable here except for evaluating the effect of wind action vibrating the liner against protruding aggregate.

The laboratory of EBA was not equipped to carry out the specialized rubber testing specified in the A.S.T.M. Standards. Enquiries made to companies in the rubber industry in Canada indicated that specialized testing was usually carried out by laboratories in the U.S.A.

It was decided to carry out a series of qualitative tests, in the Edmonton laboratory, aimed at reproducing working conditions that the liner might be exposed to. All tests were carried out on samples of Dunseal Membrane, 30 mil gauge (0.030 inches thick). Cooling of test samples was achieved by using dry ice and acetone. In this way, it was possible to realize test temperatures as low as -87°F . The test methods and results are as follows:

1. Samples showed hardening and stiffening below $+10^{\circ}\text{F}$ and began losing "elasticity" or rebound properties between -14°F to -25°F . Samples cooled to -87°F still possessed modest plasticity.
2. Samples (1 inch by 4 inch) were cooled and then folded back through 180 degrees. No sample cracking was observed at -60°F . Thirty percent of the samples cracked at -87°F .

Samples of joints were also tested in this way and proved satisfactory at -60°F but cracked at -87°F .

3. Test strips were folded back, then clamped in position and cooled to -60°F and -87°F . Some samples were then opened up while still cold; the remainder were allowed to return to room temperature before folding open. Neither set of samples showed cracking at -60°F . Both sets, cooled to -87°F , showed either surface cracking or else broke brittlely on folding back to the original configuration.
4. Joint samples were cooled to -87°F to see if joint separation would take place at cold temperatures. No separation was observed.

5. Joint samples could be pulled apart manually (tension across the joint) at room temperatures. At cold temperatures (-87°F) approximately the same stress level was required to separate the joint.
6. A sheet was cooled to -87°F , clamped in a frame and tested for the mode of penetration failure, using a quarter inch diameter rod. The sheet failed by puncturing, as at room temperature, and not by brittle "crazing".

Based on these results it would appear that the Dunseal membrane would perform adequately well under the anticipated conditions at the Eskimo Point Reservoir. However, it was recommended that the liner manufacturer be made aware of the anticipated operating conditions, and that a suitable warranty be provided with the liner installation. It should be noted that the above test results and conclusions relate to Dunseal membrane and not hypalon membranes in general. It was then decided that the final design would specify a hypalon membrane liner specifically Dunseal membrane or approved equal.

Additional Design Considerations

In addition to the foregoing design problems associated with construction of the Eskimo Point Reservoir the following significant items to lesser degree were also considered in finalizing the design:

- a. Iron concentrations at maximum ice thickness and minimum storage. This would determine the amount of dead storage to be incorporated in the bottom of the reservoir.
- b. Permafrost redistribution within the berm causing a long-term dishing effect and hydrostatic uplift problem.
- c. Requirement for underdrains and the effectiveness of the underdrains.

Special Considerations

Prior to final design the following restrictions were placed on the program and were required to be incorporated into the design as best as possible.

1. The construction was to depend largely on local equipment. In addition, the Government of the Northwest Territories provided two tandem

trucks and a 4 yard capacity rubber tired loader. These three pieces of equipment were shipped to Eskimo Point by sealift in late 1974.

2. In accordance with good government policy, every effort was to be made to use local workers on the project.
3. The reservoir was to be tendered publicly for construction and the contract completion date would be September 30, 1975.

Final Design

The final design of the new reservoir was completed in early 1975. The significant features included:

1. Construction of an above ground reservoir by a fill replacement method rather than the more conventional cut-fill methods. This would minimize ripping of frost and also equipment wear. In addition, the above reservoir would be constructed adjacent to the existing airstrip esker with the esker forming one complete side of the reservoir and a major portion of another side.
2. Lining the reservoir with an impervious membrane liner and protecting the liner from ice damage. As a result of our detailed studies, it was decided that a hypalon membrane (30 mil thickness) or approved equal would be specified. Installation of the membrane would involve three separate soil types as recommended in the geotechnical evaluation.
3. Construction of a portable pipeline approximately one mile in length. The pipeline would be specified as a high density polyethylene pipe for two major reasons: its superior cold weather characteristics, and its light weight. A special "shouldered end" suitable for victaulic type couplings would be butt-fused to each end of the polyethylene pipe such that the pipeline could be assembled and disassembled quickly each year. With 38 foot sections the assembly time was estimated to be one and a half days.
4. Construction of an intake and pumphouse. The intake would be tailored after a similar design installation by W.L. Wardrop & Association Ltd. at Cape Dorset, N.W.T., which utilized a submersible well type pump. The pump and discharge assembly is installed in an insulated heat traced double casing, which extends at an incline to below maximum

ice depth. The pumphouse, required for chlorination and electrical control, would be constructed from prefabricated urethane panels. The erection time for the building was estimated to be one day.

PART III

Construction

Early in 1975 and in co-operation with the Settlement, one International TD-25 dozer and a Hough 50 rubber-tired front-end loader were assigned to the program to supplement the equipment already allocated.

The Government of the Northwest Territories then engaged Vulcan Machinery and Equipment Ltd. of Winnipeg to overhaul the two additional pieces of equipment and ensure that the complete equipment contingent would be ready for an early summer start-up. All repairs were performed in Eskimo Point. The overhaul work was completed by mid-June.

The long-term delivery items were pretendered and purchased by the Government of the Northwest Territories in early 1975. The polyethylene pipe and victaulic couplings were supplied by Canon Plastics Limited of Montreal, a portable gasoline engine driven pump was supplied by Mumford Medland Ltd. of Winnipeg and the membrane liner was supplied by Staff Industries Canada Ltd. of Vancouver.

The pretending process revealed a similar material to the hypalon specified. By subjecting the alternate material to the same testing program as discussed earlier in this report, Chlorinated Polyethylene (CPE) was accepted as an alternate for this installation.

The delivery items were shipped by rail from their various origins to Churchill, Manitoba. From there, the items were loaded onto barges for the annual sealift to Eskimo Point. Northern Transportation Company Limited operates a sophisticated freight system based in Churchill with its barge service extending northerly along the West Coast of Hudson Bay.

During the public tendering period for construction of the reservoir, all interested contractors were invited to make a trip to Eskimo Point with W.L. Wardrop & Associates Ltd. staff and Government of the Northwest Territories officials. The site visit was initiated to acquaint the contractors with the site and potential borrow areas as well as to assess the condition and capabilities of the allocated equipment.

Parkins Construction of Edmonton was selected to construct the reservoir. The contractor's superintendent arrived in Eskimo Point in early June to organize his operation. Shortly afterward, W.L. Wardrop & Associated Ltd. personnel, with their soils consultant, arrived on site to locate the various fill materials required, to assist in the site survey, and to provide construction inspection.

With the allocated equipment, construction commenced in mid-June. The general contractor provided on-the-job training to local Eskimos and the Eskimos adapted well to the operation of the construction equipment. They also proved to be loyal workers during the long months of twelve-hour shifts per week.

The earthfill operation totalling 22,000 cubic yards of Class I material continued through the first two and one half months of construction. Concurrently, the Class II material was being stockpiled in the borrow areas to be used as a bedding layer for the membrane liner. The Class I material for the west and north dykes was primarily obtained from the immediate vicinity of the reservoir site and placed by the dozer. The east dyke was built utilizing end-dumping from the top of the airstrip which formed the south dyke.

The Class II material, 7700 cubic yards, was end-dumped along the top of the berms and subsequently spread over the slopes using the dozer. The bottom of the reservoir did not require Class II material because the initial excavation of Class I material exposed a sandy layer on the bottom which was very acceptable bedding material. Prior to the installation of the liner, the entire bedding surface was raked free of stones and other objectionable material.

Placement of the membrane liner was a crucial test for design and construction accuracy. Two representatives of Staff Industries Canada Ltd. arrived in mid-September to supervise and help install the membrane liner. A crew of twenty Eskimos was employed during this operation. Each of the eight sheets weighed approximately two tons and required the full crew to stretch them into place. Two seaming crews of three men each were formed with the Eskimos doing all of the work. The seaming operation simply involved cleaning the surface with a cloth, spreading the solvent with a squeeze bottle and completing the weld. Dwell time (time required for the cement to make the bond) was minimized by the use of electric heat guns.

Placement of a layer of protective fill over the liner (Class III material) was envisioned to be the most difficult phase of construction. To add to the difficulty, the whole program, in spite of the contractor's excellent operation, was almost one month behind schedule. Through mutual agreement between the liner supplier, contractor, and engineers, a simplified end-dumping procedure was adopted. The procedure involved dumping the material along the top of the dykes and then dozing it inward.

During the final earthwork operation the intake piping and portable pipeline were installed. By the time the earthwork operation was completed in mid-October, winter had already arrived at Eskimo Point. It was decided that it would be impractical to install the pumphouse in 1975, and the contractor should concentrate his efforts on filling the reservoir to ensure an adequate supply of water for the Settlement's water requirements.

The reservoir was filled during the first two weeks of November. Special measures were taken to ensure that the pipeline would not freeze. During the filling operation, water was being drawn from the reservoir by the Settlement. The inhabitants of Eskimo Point found the water to be a great improvement over what they had previously been drinking.

The Eskimo Point Water Supply Program will be completed in the summer of 1976. The estimated completed cost of the Program is \$660,000, excluding equipment depreciation costs and transfer costs.

SANITATION SYSTEMS FOR QUEBEC SUBARCTIC VILLAGES

by

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INTRODUCTION

The sanitary conditions prevailing in most northern settlements are continuing to be of major concern to responsible health and environmental authorities in Canada.

It is difficult to understand how a typical household in the Canadian north will soon be able to communicate with the rest of the world via satellite while means have not yet been found to provide the rudiments of sanitary facilities: a supply of clean water and the safe evacuation of body wastes. And this is not for the lack of appreciation of the problems or of interest on the part of a multitude of persons, some of whom have devoted most of their active life to bringing physical and moral comfort to the native populations.

A most plausible and simple explanation of this situation is one which has frequently been expressed before, namely the degree of adaptability of available (southern) technology to northern conditions.

In areas where established techniques could readily be applied, such as in power generation, radio communications and building construction, progress has been normal. In municipal sanitation however, the record shown that simple adaptation has often resulted in technical failures of prohibitive costs. Thus, administrators have (for too long a time) been awaiting the advent of suitable tools to answer the very dire needs of northern populations at acceptable costs. Much time has been lost and a concerted effort must now be made to provide the technical means, however imperfect and tentative, so that a major sanitation program can proceed early.

The work to be presented here was conducted as a contribution to this task with special emphasis on the needs of the Quebec section of the Canadian arctic.

THE REGION

That portion of the Province of Quebec lying north of about the 50th parallel and extending to the straight of Hudson and Ungava Bay, is a part of the Canadian north known as le Nouveau Québec. It is fully described by Wonders [1] and Hamelin [2]. Continuous permafrost is found along the north coast and discontinuous permafrost extends south to a line approximating the 55th parallel.

Population statistics (1974) for the major posts are given in Table I. The villages are listed in the sequence of their location, proceeding north along the shores of James Bay, Hudson Bay, the Straight of Hudson and Ungava Bay to the Labrador border (Figure 1).

All villages, except Fort George, Post de la Baleine and Fort Chimo, are supplied with water by means of a tanker into household reservoirs of 45 to 500 gallons each and sanitary wastes are removed in plastic bags to a dumpsite at the outskirts of town. A portion of Fort George is serviced by water works and sewers while a section of Post de la Baleine (Great Whale) acquired by the Quebec Government from the army is equipped with a water supply and sewer network. In Fort Chimo the major community buildings and some homes are equipped with sewage tanks and services by a wastewater tanker.

PRIORITIES AND PROGRAM

Study of published data on the subject and consultations within our department as well as with regional officers of Health and Welfare, Indian Affairs, and other agencies involved, led to the selection of priorities for future action:

- (1) Reduce or eliminate health hazards arising from the present methods of collection and disposal of sanitary wastes (honey bags and dumps).
- (2) Increase the volume of clean water available to each household to the minimum required for sanitation purposes and provide means for the safe evacuation of the effluent.
- (3) Select systems which could be adapted to existing households and villages, with emphasis on the needs of the small community.

TABLE 1 - POPULATIONS OF NORTHERN QUEBEC VILLAGES - 1974

	<u>INUIT</u>	<u>INDIAN</u>	<u>WHITE</u>	<u>TOTAL</u>
NOUVEAU COMPTOIR	-	600	6	606
FORT GEORGE	54	1,455	200	1,700
POSTE DE LA BALEINE	560	350	182	1,092
INOUCDJOUAC	539	-	34	573
POVUNGNITUK	749	-	46	795
IVUJIVIK	136	-	8	144
SAGLOUC	429	-	21	450
MARICOURT	242	-	12	254
KOARTAC	113	-	8	121
BELLIN	267	-	12	279
FORT CHIMO	633	-	180	813
TASIUJAK	95	-	5	100
PORT NOUVEAU QUEBEC	280	-	11	291
	<u>4,097</u>	<u>2,405</u>	<u>725</u>	<u>7,227</u>

(1) Courtesy Quebec Department of Natural Resources.

FIGURE 1
PROVINCE OF QUEBEC
PHYSICAL FEATURES



- (4) Carry out all investigative work in cooperation with other agencies and wherever possible in the field.

In order to achieve the desired results, a village sanitation system and its components must perform within specified limits of operation and service ability and within predictable and reasonable capital and operating costs.

SYSTEM STUDIES ON TYPICAL VILLAGE

The village of Inoucdjouac (Port-Harrison) was chosen for system evaluations on paper. It was one of four in the region of which the Department of Indian Affairs had previously commissioned physical studies of the site, in order to support future town planning work [5, 6, 7, 8]. The locations, size and accessibility for future field studies and the presence of a high altitude weather station of Environment Canada were major factors of our choice. A contract was awarded to Pluritec Consultants Ltd. on the basis of their extensive experience of the region and their particular knowledge of the village. The terms of reference called for:

- a) a review of the literature and other sources of information on sanitation methods and equipment applicable to the north;
- b) the preliminary design of promising systems based on proven and developing technologies;
- c) the technical evaluation and cost estimate of each system all for the purpose of,
- d) making recommendations for future work towards the goal.

Their work was recently completed and the final report will be available for distribution shortly [9].

The site study [5] and this systems evaluation report [9] provide a very detailed and well documented basis for future decisions on this and other similar villages in the region. The extensive bibliography will be found of great assistance to workers in the field.

The following is summarized from the report to which the reader is referred for a thorough understanding of the author's views.

The village of Inoucdjouac is located on the western shore of the estuary of the Innuksuak River. The village covers an area of approximately

1,100 m x 400 m (3,600 ft x 1,300 ft) including the weather station of Environment Canada. Buildings are spread out in typical fashion. The study was based on a population of 750 as projected for 1988 and the provision of service to 150 homes and related community service buildings.

The utilities deliveries network shown on the plans add up to approximately 3,500 m (11,400 ft).

A - Water supply

The characteristic disadvantages and costs of trucked water systems are well known. To meet the sanitation objectives of a reliable, clean and adequate water supply to each home, a piped system as described is the only acceptable solution found. Use water saving appliances and practices in the homes; provide for a design flow of 150 l/pers/day (33 ig/c/d); provide storage for one day of supply; distribute by looped, electrically traced, insulated piping, shallow buried, equipped with pitorifices and return house connections.

B - Sewage removal

Provide either:

- Ba) Sewage collection network and treatment or
- Bb) Individual or household treatment with discharge to surface drainage ditches.

Ba - Sewage collection network and treatment

Install small diameter, pressurized, electrically traced and insulated sewage collection loop, shallow buried with a disintegrator pump in each house.

Treat by extended aeration activated sludge process and discharge by pressure pipe to Hopewell Straights. This system uses demonstrated technology and could be built without delay.

Bb - Individual household disposal systems

A large number of systems and apparatus were examined as alternatives to a community sewage and treatment system. No scheme was considered to be ready for early application to a full village. Additional work is

required on the performance and reliability of components in service, on their acceptability and maintenance requirements. One system offers some promise for development but (the present choice) is subject to revision as experience is gained and new devices are proposed.

Collect and treat body waste by means of a composting toilet of the kind sold by HUMUS*. Remove residue periodically to village humus pile. Collect and treat grey water by means of individual sand filter or other suitable device; disinfect with hypochlorite or other means and discharge by siphon into nearest drainage ditch. Improve surface drainage ditch network in village to prevent accumulation of treated effluent. Ice cones building up in the winter will have to be dealt with periodically.

C - Community disposal of solid wastes

The health hazards from the open dump disposal of sanitary wastes in bags can be eliminated by incineration in a community facility.

Ca - An incinerator design suitable for household garbage and sanitary wastes was evolved as a basis for development. The fuel consumption and mechanical features need to be improved upon during development.

Cb - For household wastes alone a community incinerator of much simpler design and low fuel consumption is proposed. It is suggested as a complement to one of the sanitation schemes proposed above.

Costs

Cost estimates were developed as an aid in the appraisal of each scheme. These are very preliminary and although carefully worked out,

* HUMUS Toilets Corp. Ltd.
8156 Jean Brillon, Ville LaSalle, Que. Canada H8S 4B6.

they should not be relied upon for other purposes. Costs for undeveloped systems are obviously subject to much larger errors. Data from the report are summarized in Table 2.

The costs of each step of a multi-stage program are projected (in 1975 dollars) in Table 3. It suggests that our first objective of eliminating the sanitary waste from the village streets can be attained at relatively modest costs as soon as acceptable apparatus are proven out.

General Observations

The author of the report makes further observations worth noting here:

- a) Most of these villages were built without a coordinated plan. It might be wise to consider some rearrangement of the present layouts before major investments are made for utilities which would have the major effect of perpetuating undesirable planning features.
- b) The lack of skilled operators in this and other similar villages could jeopardize the effectiveness of the treatment: operators should be trained well ahead of project implementation.
- c) Little is known of the impact of raw domestic sewage in the sea in this area. Little data is to be found in the literature. It would be useful to know which is closer to the truth, between the two extreme views that the sea is the best wastewater treatment medium and that which describes it as a giant septic tank.
- d) Profit seeking enterprises are not, generally, investing research efforts to find solutions to these problems; expected volume of sales and profits are not sufficient. Too few applied research projects have been conducted or sponsored by public funds in the field of wastewater treatment in the north.
- e) In view of the limited results which have obtained from the efforts so far deployed to find original solutions

TABLE 2. PRELIMINARY COST ESTIMATES OF SUGGESTED SANITATION SYSTEMS

SCHEME	DESCRIPTION	CAPITAL	YEARS	AMORTIZATION /YEAR	OPERATION /YEAR	TOTAL /YEAR
A	Water storage & supply (1) per house	\$615,000. 4,100.	20	\$72,240. 481.	\$25,000. 167.	\$97,240. 648.
Ba	Sewage network and treatment (2) per house	\$986,280. 6,575.	20	115,850. 772.	48,000. 320.	163,850. 1,092.
Bb	Individual household treatment Toilet (per house)	\$ 1,320.	7	\$ 217.	\$ 100.	\$ 371.
	Filter (per house)	650.	15	85.	30.	115.
	Total (per house)	1,950.		302.	130.	486.
	Total village	295,500.		45,300.	19,500.	72,900.
C	Community Incinerator					
	Ca - Refuse & Sanitary per house	\$ 155,000. 1,033.	15	\$ 20,380. 136.	\$ 58,000. 387.	\$ 78,380. 523.
	Cb - Refuse only per house	135,000. 900.	15	17,750. 118.	27,000. 180.	44,750. 298.

(1) Water treatment not included in costs.

(2) Includes costs of recirculation, heating and treatment by extended aeration.

TABLE 3. PROJECTED COSTS OF SANITATION PROGRAM BY STAGES
Based on Individual Household System

STAGE	DESCRIPTION	EQUIPMENT	INITIAL Cost	ANNUAL Operating Cost
I	Sanitary waste treated in house	Composting Toilet	\$ 1,320.	\$ 100.
II	Grey water treated in house (1)	Filter & Unit	650.	30.
I & II	Total		<u>\$1,970.</u>	<u>\$130.</u>
III	Community water supply	Storage & Mains	4,100.	167.
I & II & III	Total for complete system -(per house)		<u>\$6,070.</u>	<u>\$297.</u>

(1) Increase water storage capacity in houses, frequency of deliveries and add wash basins in homes.

to problems particular to the Canadian north, it might be opportune to set up a research and documentation center. Supported by all groups having an interest in northern development and staffed by Canadians from coast to coast, this would answer a need of our time for more coordinated efforts and improved technology transfer.

Application of Results

This study was undertaken as much as a research modelling exercise to assist in the identification and study of solutions, as for the purpose of a preliminary design for the village. We would like to see this research exercise pursued using the same model village, and fitting new shemes and cost data as they are proposed. This would provide a periodic evaluation of real needs, project objectives, costs and rate of progress of our research program.

In the meantime, civic and regional administrators will be kept fully informed and invited to comment the study and assist in setting priorities for our future work. The selection of this village and our preference for certain solutions for development should not, however, be interpreted as recommendations in the choice of this village or of that system for early implementation.

APPARATUS DEVELOPMENT

Composting Toilet

A promising self-contained composting toilet manufactured in Sweden under the trade name of Mull Toa appeared on the Canadian market early in 1974 under the name of HUMUS Toilet.

The working principles, the mechanics, the installation and operation are all extremely simple. Sales, to date, in Canada have been reported in excess of four thousand units (4,000) and the customers are reported to be generally satisfied. We undertook to carry out an evaluation of its use in the north. Four units (No. 5) were supplied to the Dept. of Indian Affairs late 1974, and shipped to Povungnituk. Two were installed in Inuit homes and two in (white) staff homes. After some problems of flooding, presumed caused by defective installation or overloading three are reported to be in operation, at about 60% of rated capacity of five persons. One

failed from flooding due to massive overload (eight persons) and has been removed. The two units in the native homes will soon be replaced by Model 10 (10 persons) to eliminate the flooding problem. Acceptance has generally been good and the Band Council has been following the progress with much interest. Reports, generally favorable, received on other installations in the north (Igloolik, Pagnartung) were made available to the Northern Technology Centre. This subject being dealt with by others in this symposium we will say no further, other than that we regard this as a very promising solution to one of our problems and that all efforts to advance its development and acceptance should be supported.

Grey water treater

The need for this device and its place in the scheme should be clear from the above. Some typical devices are discussed in the report [9]. Agreement should now be reached on performance criteria, flow capabilities, etc. It is hoped that sand filtration and disinfection might be adequate and that a filter design could be evolved for field assembly and repair. An alternative would be the use of a disposable cartridge filter element. Other component parts will be identified from time to time and anyone fitting in a promising system should be found and developed, in house, if not by the trades until the bill is fully met.

Distribution hardware

Much of the projected costs are going to the "outdoor plumbing system", its installation, operation and maintenance. We have a distinct feeling that size reduction and prefabrication of standard fittings suitable for assembly in the field would assist in reducing this item of costs. In this regard we should like to have an estimate of the overall cost of a water distribution network designed to supply homes at the average daily water flow (rather than the peak hourly rate) from a small village storage system, and feeding into individual storage tanks in each home. Methods of tracing are also in need of improvement. For example, the use of the waste heat from the powerhouse should be made practical as soon as possible.

CONCLUSIONS

The threat to health and environment arising out of the present sanitation practices in Canadian northern settlements should be eliminated. However, the excessive costs of conventional sanitation methods applied in the north are a serious deterrent to general improvement programs.

A detailed study was made of the needs of a typical northern Quebec village - Inoucdjouac - together with the feasibility of alternative sanitation methods including novel systems promising lower costs.

The study showed that the treatment of liquid wastes individually in each home using a composting toilet, grey water filtration and disinfection, together with a community water supply network offers a promising solution for the near future. Indicated capital costs (per house) are about \$2,000 for equipment in the home and \$4,000 for the water works. Operating costs are estimated at \$130 and \$300, respectively. This is about 57% of the capital and 25% of the operating cost of a conventional system.

An evaluation of the use a composting toilet in the north was carried out and progress to date is quite promising. Its acceptance would allow the early elimination of a major health hazard - the honey bag system - at an estimated cost of \$1,300 per home with \$100 per year for operation.

The need for a grey water filter for the home has been established and work should proceed to evaluate equipment against reasonable targets and making use of recent developments in shipborn systems, etc...

The use of a real village as a model to evaluate feasibility and costs of systems is revealing. It would be well to repeat the exercise periodically as a guide to and means of evaluating our progress with the work.

Future activities in this program will give rise to more field testing, evaluation and demonstrations. Interest in the outcome of this work is very real and widespread. It should be possible to muster the necessary resources and proceed with an evaluation project in the field during the coming year and move to a village size demonstration in the next.

REFERENCES

1. Wonders, William, C. - Editor
 "Canada's Changing North I"
 The Carleton Library, Number 55
 McClelland and Stewart Limited, Toronto, 1971.
2. Hamelin, Louis Edmond
 "Nordicité Canadienne"
 Les Cahiers du Québec
 Hurtubise, H.M.H. Ltée., Montréal, 1975
3. Davis, Eric, P. - Editor
 "Symposium on Wastewater Treatment in Cold Climates".
 Saskatoon, Sask. Canada, Aug. 1973
 Environment Canada Report No. EPS-3-WP-74-3, March 1974
4. McCallum, Bruce
 "Developing Technologies for a Conserver Society in Canada"
 Environment Canada, March 1975
5. "Etude physique du site village de Saglouc, Nouveau Québec".
 Report by: Les Consultants Pluritec Inc.
 for Department of Indian Affairs and Northern Development
 (Quebec Region) January 1974.
6. "Etude physique du site village de Saglouc, Nouveau Québec"
 Report by: Les Consultants Pluritec Inc.
 for Department of Indian Affairs and Northern Development
 (Quebec Region) March 1974
7. "Rapport d'étude physique du site de Payne Bay"
 Report by: Lemieux, Morin, Bourdages, Doucet, Simard & Associés.
 for Department of Indian Affairs and Northern Development
 January 1974.
8. "Rapport d'étude physique du site de George River"
 Report by: Lemieux, Morin, Bourdages, Doucet, Simard & Associés
 for Department of Indian Affairs and Northern Development
 January 1974.

9. Inoucdjouac, Nouveau Québec

"Etude de Systèmes, Aqueducs, Egouts, Résidus Ménagers"

Report by: J.C.J. Héroux, P. Eng. - Les Consultants Pluritech Inc.
for Environment Canada (Quebec Region) - Montreal, December 1975.

MUNICIPAL SERVICING OF NORTHERN COMMUNITIES

- WHERE DO WE FALL SHORT?

by

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I compliment the Northern Technology Centre and the Department of Civil Engineering at the University of Alberta for holding this meeting and for choosing this topic. I have attended other conferences on the north, or on environment, or on both, which were less than satisfying. I believe I speak for all of us, when I say that we have learned a lot during the past three days and have enjoyed it at the same time. The topic is important, timely and has sufficiently well defined boundaries to stand a chance to explore matters in some depth and perhaps to result in some changes in servicing after this meeting is over. So much for the good news.

I, ladies and gentlemen, thought that I was going to be part of a panel, who were going to share the blame with me for this wind-up session. I received second and third program notices, and finally the yellow copy at the conference - and I am still alone. But I think there is an advantage in this for you and me. I get to talk longer and first, and you, if you agree with some of what I will say, can tell yourself that you have been right all along, and if you disagree with me, you can tell yourself "what does he know, after all it's just one man's opinion".

Some of you know me, some of you don't. In both cases you may well ask, what are my qualifications to speak on "where do we fall short, where should we go from here in servicing northern towns"?

I have asked myself that question, and I'd better give you an answer. Well, first of all, I am a civil engineer, and a sanitary one at that. I have some experience, although a good deal less than many of you. Perhaps the real reason is my inability to keep my mouth shut, much of the time. I had advice from several of you during the past three days on what to say and I wrote some of it down. Here is one: "Put the Department of the Environment out of the N.W.T.", by someone in another Federal

government department; "We can take over from the Department of Indian Affairs and Northern Development", from someone in the Department of the Environment; from one of our Alaskan friends: "Tell us how you got rid of all government agencies, and we will follow your example"; from a government administrator besieged by consultants: "Why do they always discover the north when things are slow in the south?" This one I am not even going to read! Remember now, I just read these suggestions, I did not say them.

Now let me concentrate on the topic: "Municipal Services for Northern Communities." Out of necessity I will wander a bit from purely technical matters. Here are my assumptions, based on a good deal of listening to people who know better than I do what may happen in the north by the end of this century:

- We will develop the resource potential to a much greater extent than now, particularly in oil and gas. With it will come many other changes and the money for it.
- We will come to a more just agreement with our native brothers and sisters that will give them their fair share of the wealth, including for those who desire it to live as their forefathers have.
- We will find, somehow, the wisdom of developing in harmony with the northern environment
- Communities, now existing or to come, will develop and grow, but will not explode. I do not foresee large communities, of the size of those in Siberia, for a very long time, if ever. Perhaps some of our communities, now 5000, will grow to 10,000 or even 20,000. But there will also be many communities, which will stay, by choice or otherwise, small, a few hundred people.

What will it take to get better municipal services in our communities? What comes to my mind is this: people, policies and effective organizations, money and technical know-how.

We have been talking about many examples the past few days of how technical things went wrong, and why, and that's refreshing. Too often people only talk about their successes. But as important as technical know-how is, it is only a part of the story. Let me say a few words about where I think we fall short in getting better services under my chosen headings of people, policies, money and technical know-how.

By people, I mean people who live in the community and use the services; local leaders and administrators, who are responsible for the services; planners and consultants, who design the community and services; and industry, who build the systems. Among all those we now find responsible and irresponsible citizens. That's the way it is everywhere. Services are built to serve the people. We have often forgotten this and "improved" services in a community without their say and sometimes against their liking, on the pretense that we know better than they do. If you are ever going to develop the so necessary community spirit in places that have such huge differences in background, outlook and aspirations as do exist between oldtimers and newcomers, who are often transients, you better give them a say on how their communities should be. Provide them with the best information available on alternatives, costs, etc., and make them pay for the consequences of their decision (even if it is part of an overall subsidy to the town and the people), but let them decide. Public participation is difficult, time consuming, frustrating, but it must be done. Let me highlight one thing Bill Ryan said yesterday:

"The one essential thing to have in a community which will allow successful operation of services is one (or a few) individuals, who will take a sincere interest in seeing that the facilities are taken care of." Amen!

I am confident that by giving them more local self-government, there will be more such individuals as community leaders. I am also confident that we will have the kind of dedicated administrators, consultants, contractors, etc. who care enough about the communities they serve to serve them well.

Now to politics and government agencies. We all know of services which have been built for purely political reasons, and which have been a total waste of money. Expensive utilidors serving native homes, which have

no plumbing facilities, and no hope of having the owners pay for the connections or the necessary home improvements. We heard of the case of having to install secondary sewage treatment, to conform with a law, which made eminent sense elsewhere, but not in the northern community, which could have used this money in much better ways. It would be easy to blame all the politicians and administrators and say that they are incompetent. But that is not the case, in most instances at least. They are trying to do their job, within their framework of authority. Often they are not aware of the overall problem, or are not allowed to act on their conviction. Within a short period of years we have gone from almost total neglect of the north to a spiderweb of overgovernment. My only principle to improve things would be to put the decision-making authority, within some overall guidelines, at the lowest possible level. The move of the federal government to transfer much of the power to the NWT government at Yellowknife was a good move. We need more of it in time to have eventually northern communities operate the same way as southern communities do.

In the environmental field we have seen the huge expansion of departments of the environment in almost all western countries in recent years. This has been a step forward, but there are problems of jurisdictional disputes with other government agencies, provincial governments, etc. I think we must try very hard to reduce this situation of overlap of responsibilities. We certainly fall short in this area now.

Money will be required for research, experimentation and the building of services. Sometimes I think less money would improve the situation, we would be forced to engineer better than we do. But to improve sanitation overall, lots of money will have to be spent over the next 25 years. Northern work, if not unique to Canada, is nevertheless a very important Canadian problem. We can import research and technology to solve some of our southern environmental problems, we cannot for our northern problems. The Russians work on a different scale. I don't believe in small community servicing that we can learn that much from them. We need to contribute more. I suggest to those of you in the audience who have any influence on setting priorities for limited funds, to put northern work on a much higher priority than up to now. So far very little money has been spent on planned research and experimentation on municipal

servicing and environmental protection. We have, however, done an expensive program of full scale experimentation.

Now to technical know-how: I have heard it said several times that every situation is unique in the north and requires its own solution. I appreciate this point but don't agree with it entirely. We have learned a lot in the past fifteen years on servicing northern communities. We have done, however, a poor job of setting down what we know and what we don't know. So it is difficult for a newcomer, and we need them, not to go about reinventing the wheel. I would like to recommend, as a practical outcome of this excellent meeting, that a much smaller group of experienced people from Alaska and Canada undertake to prepare a 'manual of current practice in municipal servicing in the north'. We need not worry about arguing about the 'best' utilidor - it does not exist - but put down several that have worked and were not too expensive, and also those that did not work. It should deal with many of the issues raised in this meeting and provide the best consensus of what we know now. We will, of course, have to go on from there to provide better solutions, but it would give us a good common start and be of immense help to newcomers.

I list only a few things which should be covered in such an undertaking:

- Guidelines for community planning to satisfy both people and reasonable servicing costs.
- Guidelines for water consumption under different levels of service standards.
- Guidelines for expected waste strengths for communities and camps under different servicing standards.
- Guidelines for investigations to determine the feasibility of above and below ground services.
- Success and failures of utilidors and pipelines.
- Vacuum and pressure sewer systems - where are they a good alternative and how should they be engineered?
- Guidelines to evaluate when one should change from a trucked system to a piped system.

- Comparison of the central supply concept as used in Alaska and the individual delivery system as used in NWT.
- Materials guidelines.
- What about fire protection, etc.

Joe Alter spoke of the waves of construction activities in the north associated with various events, such as World War II. We are now already a bit late on the start of the next wave, oil and gas development, and let's face it squarely, we as a profession cannot say that we are ready this time. This task of putting down best current practice is urgent. A consortium of the Northern Technology Centre and their Alaskan counterparts would be a good group to do this, with the help of consultants, industry and the universities. It is a sizable job and will need to be funded substantially. Otherwise let's not do it.

Let me finish by looking back a few years when most of us were not in this work and only a few concerned and committed people, against pretty big odds, tried to do their best to help improve sanitation in the north. Sometimes we get too smug about our more recent accomplishments, and perhaps how much more sophisticated things will be in 25 years. I think we owe a lot to those early tireless workers, and I shall name two of them, as representatives of all others: Joe Alter and Jack Grainge, who both are with us today. If we and those who will come after us show the same dedication and care as they have, I have every confidence that 25 years from now we will be able to look back on our achievements with satisfaction and justifiable pride.

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